

# AERONAUTICS

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## THIRTEENTH ANNUAL REPORT

OF THE

## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS



1927



UNITED STATES  
GOVERNMENT PRINTING OFFICE  
WASHINGTON  
1928

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## LETTER OF SUBMITTAL

*To the Congress of the United States:*

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the thirteenth annual report of the committee for the fiscal year ended June 30, 1927.

Attention is invited to the remarks of the committee on the death of its late chairman, Dr. Charles D. Walcott, on whose advice the committee was established by the Congress in 1915. At a time when there was but little appreciation of the value of aeronautics and but slight conception of its problems, Doctor Walcott had the vision to see the need for organized scientific research on the fundamental problems of flight. The establishment of the National Advisory Committee for Aeronautics, the development of its usefulness in the formulation of policies, and the results of its labors in the field of research are a tribute to the leadership of Doctor Walcott and stamp him as a great constructive force in the upbuilding of American aeronautics.

The technical improvement in the performance and efficiency of aircraft for all purposes, the policy of the Government in the regulation and encouragement of aviation, and the great impetus given to aeronautical development during the past year by the transoceanic flights of Lindbergh and others have combined to cause a broader recognition of the practicability of aircraft as a means of transportation that I believe is destined to play an ever increasing part in the advance of civilization.

The attention of the Congress is invited to Part V of the committee's report, presenting a summary of the present state of aeronautical development. It is gratifying to note the committee's opinion that aeronautical progress in the United States during the past year has surpassed the hopes of a year ago, and that the present governmental policy is primarily responsible. I concur in the committee's judgment that further substantial progress in aeronautics is dependent largely upon the continuous prosecution of scientific research.

CALVIN COOLIDGE.

THE WHITE HOUSE,  
December 8, 1927.



## LETTER OF TRANSMITTAL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,  
*Washington, D. C., November 26, 1927.*

MR. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (Public, No. 271, 63d Cong.), I have the honor to transmit herewith the thirteenth annual report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1927.

During the past year the committee lost the services of its chairman, Dr. Charles D. Walcott, who died on February 9, 1927. He was the founder of the committee and for 12 years had served actively in the development of American aeronautics and in the framing of national policies. His services in the development of American aeronautics, especially during the war period, were of inestimable value to the Nation. Attention is invited to a brief summary of his major contributions to aeronautics presented in the beginning of the committee's report.

The year 1927 witnessed substantial and gratifying progress in the scientific study of the fundamental problems of flight and in the technical development of aircraft for all purposes. This year will always be noted for remarkable demonstrations of the uses of aircraft. Such failures as occurred emphasize the great necessity for adequate preparation and for further scientific research and development.

Attention is invited to Part V of the committee's report presenting an outline of the present state of aeronautical development. The report concludes with a summary of the factors that have contributed to the advancement of American aeronautics to the point where the development and use of American aircraft, military, civil, and commercial, are such as to meet the present demands or to indicate the lines of progress in the years to come.

In the opinion of the National Advisory Committee for Aeronautics the present gratifying position of American aeronautics and the growing rate of progress in its development are due primarily to the effective prosecution of the Government's sound aeronautical policy.

The committee reiterates its belief in the necessity of continuous fundamental research as the basis of continuous substantial progress.

Respectfully submitted.

JOSEPH S. AMES,  
*Chairman.*

THE PRESIDENT,  
*The White House,*  
*Washington, D. C.*

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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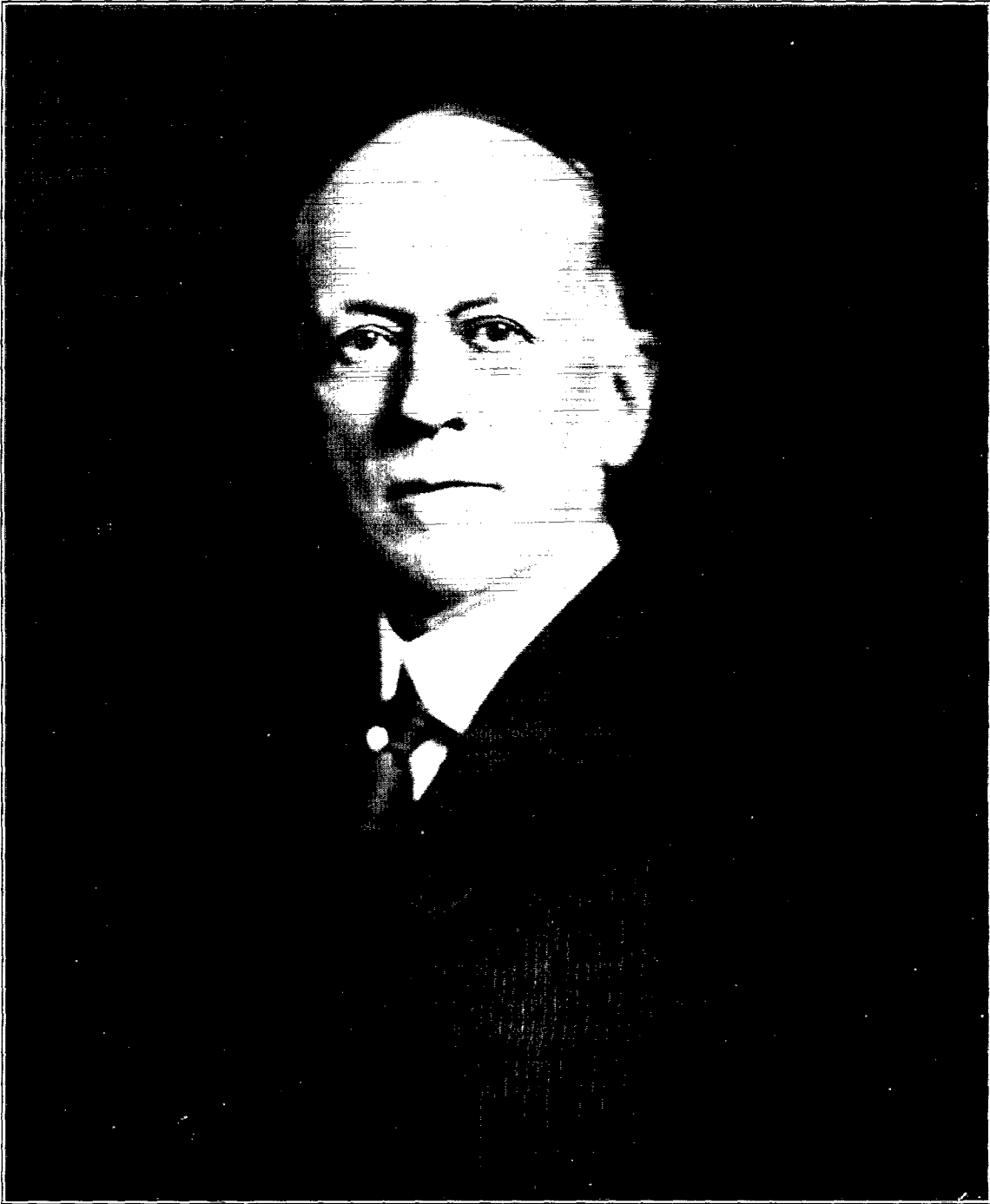
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CHARLES D. WALCOTT

1850-1927

Late Chairman National Advisory Committee for Aeronautics

# THIRTEENTH ANNUAL REPORT OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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WASHINGTON, D. C., November 26, 1927.

*To the Congress of the United States:*

In accordance with the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its thirteenth annual report for the fiscal year 1927.

In Part I of this report the committee comments on the death of its late chairman, Dr. Charles D. Walcott, describes its organization, states its functions, outlines the facilities available under the committee's direction for the conduct of scientific research in aeronautics, explains the activities and growth of the Office of Aeronautical Intelligence in the collection, analysis and dissemination of scientific and technical data, and presents a financial report of its expenditures during the fiscal year ended June 30, 1927.

In Part II of this report the committee describes its general activities including those in connection with the consideration of aeronautical inventions and designs and the procedure followed by the committee in its relations with inventors and with the Aeronautical Patents and Design Board, which consists of the three assistant secretaries for aeronautics in the departments of War, Navy, and Commerce. The committee also reports on its relations with the aircraft industry and its cooperation with the Army and Navy and other American agencies, governmental and private, and with the British Aeronautical Research Committee.

In Part III the committee presents the reports of its standing technical subcommittees on aerodynamics, power plants for aircraft, and materials for aircraft, which include statements of the organization and the functions of each and of the progress of investigations conducted under their general cognizance in laboratories governmental and private.

In Part IV the committee presents summaries of the technical reports published during the past year and enumerates by title the technical notes, technical memorandums, and aircraft circulars issued.

In Part V the committee presents its views as to the present state of aeronautical development with special reference to the technical development of aircraft. The report closes with a summary of the progress made during the past year and of the factors that have contributed to the advancement of American aeronautics.

## THE DEATH OF DR. CHARLES D. WALCOTT, CHAIRMAN

Dr. Charles D. Walcott, chairman of the National Advisory Committee for Aeronautics, died at his residence in Washington on February 9, 1927. He was one of the original 12 members appointed by President Wilson when the committee was established by law in 1915, and represented the Smithsonian Institution, of which he was the Secretary. Despite his activity in other fields, he was a leader in the development of aeronautics in America. His great foresight and genius for organization were brought to bear at a time when there was but little appreciation in America of the value of aeronautics and but little conception of its problems. Although the scientific world recognized him as preeminent in his chosen field in geology and had honored him accordingly, and although the public generally knew something of his career as Director of the Geological Survey, as Secretary of the Smithsonian Institution, as president of the National Academy of Sciences, and in other capacities, the American people knew little of his contributions to the development of aeronautics in America.

Shortly after succeeding the late Dr. Samuel P. Langley as Secretary of the Smithsonian Institution and before the outbreak of the World War, he secured from the Board of Regents of the Smithsonian Institution a resolution reopening the Langley Aerodynamical Laboratory and organized under the Smithsonian Institution an advisory committee of the Langley Aerodynamical Laboratory. That committee consisted of 12 members serving without compensation under the chairmanship of Doctor Walcott. It held several meetings but was soon disbanded because of the recognition of the need of public funds which it could not obtain, as it had not been created by law. In 1914, shortly after the outbreak of the war in Europe, Doctor Walcott presented to the Congress of the United States his views as to the need for organized scientific research in aeronautics and was successful in securing the establishment by law of the present National Advisory Committee for Aeronautics to study and investigate the fundamental problems of flight. The act establishing the committee was approved March 3, 1915. At the organization meeting held in the office of the Secretary of War, Lindley M. Garrison, Doctor Walcott was elected chairman of the executive committee. He was reelected annually until 1919, when he was elected chairman of the entire committee. The latter position he continued to fill by annual reelection until his death.

It was largely because of his personal responsibility for the results accomplished by the committee that official publicity during his lifetime was not given his constructive work for the upbuilding of American aeronautics. His colleagues on the committee at the present time, including four who have served since the establishment of the committee, feel that it is now a duty to state some of the facts regarding the influence of Doctor Walcott upon the development of aeronautics in America. The limitations of a public document preclude the presentation of the whole story in this report. Some day the historian or the biographer may place before the American people, and before American youth in particular, the whole romantic story of his life—of his start as a clerk in a hardware store, and of his rise on sheer personal merit and accomplishment to the very pinnacle of the scientific world. His colleagues on the committee, however, must rest content with the presentation in this report of the simple facts regarding his public service as a member and official of this committee. Accordingly his further major contributions to the progress of American aeronautics are briefly summarized chronologically as follows:

On June 8, 1916, there was held in Doctor Walcott's offices at the Smithsonian Institution a meeting of the executive committee of the National Advisory Committee for Aeronautics which was attended by representatives of the then existing aircraft and aircraft-engine industries. The purpose of that joint conference was to awaken American manufacturers to the need for the development of a more reliable and more efficient aircraft engine. It was the first general meeting of representatives of the American aircraft industry and many of them were reluctant to speak in the presence of each other. That meeting led directly to the formation of a subcommittee on power plants for aircraft and it is significant to note that within 12 months the first of the famous Liberty engines was undergoing tests.

In the fall of 1916 Doctor Walcott was a leader in securing the agreement of the Army and Navy to a plan for a joint Army and Navy experimental field and proving ground for aircraft upon which would be located the committee's research laboratory. He served as chairman of a special committee to select a site, which led directly to the selection of the site now known as Langley Field, Va. On this field is located the research laboratory of the committee known as the Langley Memorial Aeronautical Laboratory, where scientific research on the fundamental problems of flight is conducted under the committee's immediate control.

The progress of the war in Europe forced a realization of the increasing importance of aircraft in warfare, and in the fall of 1916 the Army and Navy began to expand their air organizations. This movement was only well started when in December, 1916, a patent war loomed in the American aircraft industry. The Wright-Martin Aircraft Corporation, holder of the basic Wright patents, served notice on the other aircraft manufacturers that they must take out licenses and pay royalties for the right to manufacture aircraft. The Curtiss Aeroplane & Motor Co. (Inc.), which held a number of important patents, including basic seaplane patents,

then served similar notice on the other members of the industry. The results were that the cost of aircraft to the Government advanced rapidly and to such an extent as to prevent the procurement of the number of airplanes desired by the Army and Navy within the limits of funds available; and the manufacturers who received orders in quantities which called for expansion of facilities were embarrassed by the pending or threatened patent litigation and were unable to obtain the necessary funds with which to expand, so that the Government, although contracting to pay higher prices, was not able to obtain deliveries of aircraft. In this state of affairs the War and Navy Departments officially called upon Doctor Walcott to have the Advisory Committee study the problem with a view to working out a solution. Doctor Walcott called several conferences with representatives of the various factions in the aircraft industry, and later appointed a subcommittee on patents of the National Advisory Committee. The result was the evolution of a "cross-license agreement" among the manufacturers, which put an end to the patent war and made it possible for the manufacturers to obtain capital to finance their expansion projects. Volumes have been written in criticism and in defense of the cross-license agreement in the aircraft industry. It has everywhere been upheld, first by the Attorney General, then by the courts, and lastly by the Comptroller General. Since its inception there has been no further patent warfare in the aircraft industry.

Coincident with the discussion and efforts to solve the perplexing patent situation was the imminent menace of America's entry into the World War. In March of 1917 Doctor Walcott called meetings of the aircraft manufacturers, acquainted them with the prospect of a greatly expanded aircraft building program, and urged upon them the necessity of expanding their facilities for production. He presented to the industry an outline of the first three-year American aircraft building program. In connection with this activity, Doctor Walcott conducted by telegraph a survey of the productive capacity of the industry as to aircraft and engines, with respect to the capacity at that time, capacity within six months, and capacity at the end of a year. The replies received were discouraging. He organized a subcommittee on production to work with the industry. Within a month he became convinced that the problem of aircraft production in quantities was so difficult as to require the attention of the ablest business and professional men that could be organized for the purpose. Accordingly he secured the adoption of a resolution by the National Advisory Committee for Aeronautics, recommending to the Council of National Defense that it organize an Aircraft Production Board to consider the situation in relation to the quantity production of aircraft and that a joint technical board of the Army and Navy for determining specifications and methods of inspection for aircraft be also organized. The Council of National Defense approved the committee's recommendations without delay, and Doctor Walcott turned over to the Aircraft Production Board all the records previously gathered by the National Advisory Committee for Aeronautics' subcommittee on production. The Congress of the United States within a few months enacted the famous \$640,000,000 appropriation act for aircraft and changed the status of the aircraft production board to that of an independent establishment known as the Aircraft Board.

Doctor Walcott called a conference to consider the problem of training aviators for the war which led to the calling of a conference of university presidents on April 30, 1917, to organize the training program.

While the foregoing policies were discussed and approved as actions of the National Advisory Committee for Aeronautics, their vital constructive force reflected primarily the broad vision and genius for organization of Doctor Walcott. In addition to those more important activities, he was an active leader in bringing about the following:

- The inauguration of the air mail service, discussions on the subject beginning in committee meetings in December, 1916;

- The establishment of the Office of Aeronautical Intelligence of the National Advisory Committee for Aeronautics in 1918;

The organization in 1919 of the Interdepartmental Committee on Aerial Photographic Surveying and Mapping, which led to the creation by Executive order of the present Board of Surveys and Maps of the Federal Government;

The formulation and approval by the Government of the first national aviation policy in 1920;

The encouragement of organized scientific research in cooperation with the Army and Navy;

The formulation of basic principles for the Federal control and encouragement of commercial aviation, beginning in 1919 and continuing to the enactment of the air commerce act of 1926.

He was a champion of progress and an inspiring leader. During the war period he rendered invaluable service to aeronautics in advising with and assisting the heads of the Army and Navy air organizations. He won for the committee the confidence and respect of the President, the Congress, the industry, and the public, and raised the dignity of membership on the committee to such a plane that no person has ever declined appointment on the main committee or on a subcommittee, although such service is without compensation.

At a special meeting of the members of the National Advisory Committee for Aeronautics, held in the city of Washington, D. C., on February 11, 1927, Dr. Joseph S. Ames, chairman of the executive committee, announced the death on February 9, 1927, of Dr. Charles D. Walcott, chairman of the National Advisory Committee for Aeronautics, whereupon by unanimous vote it was—

*Resolved*, That the members of the National Advisory Committee for Aeronautics do adopt and approve the following tribute to the memory of their late distinguished chairman.

Doctor Walcott was not only a great scientist; he was a great man. His mind was that of a true scientist, a skilled executive, and a trained diplomat, and withal he was an inspiring leader of men, and a man beloved by all his colleagues owing to his rare personal qualities. His broad interest extended to many branches of science and in his chosen field in geology he had no equal.

But we are met to-day in special session to praise his memory for his contributions to the new science of aeronautics. His was the vision that saw the need for organized scientific research on the fundamental problems of flight; his was the influence that caused the Congress of the United States to establish a National Advisory Committee for Aeronautics to supervise and direct the scientific study of the problems of flight. Appointed as one of the original 12 members of the committee in 1915, he served continuously until his death as our chief inspiration. From 1915 to 1919 he was chairman of the executive committee and from then until his death he was chairman of the entire committee. His was the leadership during the period of the Great War; then and since, his influence drew to the public service without compensation some of the best minds of the country and organized them into a cooperative effort for the advancement of the science of aeronautics. That he has in the field of aeronautics labored as successfully and as well as in other fields of his endeavor is attested not merely by the personal admiration and esteem of his associates on this committee, but more especially by the record of progress in American aeronautics, and by the character, stability, and standing of the research organization which has been developed by the committee under his guidance. If he had done no more for his country than he did in advancing the science of aeronautics alone, his fame would rest secure.

The world at large does but little appreciate the true greatness of this man. We who have had the privilege of serving with him as members of the National Advisory Committee for Aeronautics can only say that we are proud to have been associated with him, and we mourn his death as a loss to the entire scientific world and a distinct and irreparable loss to the science of aeronautics.

*Resolved further*, That a copy of these resolutions be engrossed and sent to the family of Doctor Walcott with an expression of our deep sympathy in their great loss.

In transmitting the engrossed memorial to the widow of Doctor Walcott, Dr. Joseph S. Ames, chairman of the executive committee, stated on behalf of the members that "Doctor Walcott was the father of the National Advisory Committee for Aeronautics and the chief constructive force in the upbuilding of American aeronautics" and that "The recollection of his wise counsel and inspiring leadership will serve to stimulate us in the future as it has in the past, to the end that our country may ever be in the vanguard of progressive nations in the development of aeronautics."

## PART I

### ORGANIZATION

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#### FUNCTIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915. The organic act charged the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

Supplementing the prescribed duties of the committee under its organic act, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics, for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of fundamental problems submitted by the War and Navy Departments with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, and Canada.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air organizations and other branches of the Government, and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it.

By act of Congress approved July 2, 1926 (Public, No. 446, 69th Cong.), and amended March 3, 1927 (Public, No. 748, 69th Cong.), the committee has been given an additional function. This legislation created and specified the functions of an Aeronautical Patents and Design Board, consisting of an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce, and provided that upon favorable recommendation of the National Advisory Committee for Aeronautics the Patents and Design Board shall determine questions as to the use and value to the Government of aeronautical inventions submitted to any branch of the Government. The legislation provided that designs submitted to the board should be referred to the National Advisory Committee for Aeronautics for its recommendation and this has served to impose upon the committee the additional duty of considering on behalf of the Government all aeronautical inventions and designs submitted.

### ORGANIZATION OF THE COMMITTEE

The committee has 12 members, appointed by the President. The law provides that the personnel of the committee shall consist of 2 members from the War Department, from the office in charge of military aeronautics; 2 members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than 5 additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. The law further provides that all members as such shall serve without compensation.

In February of this year, the committee suffered irreparable loss in the death of its chairman, Dr. Charles D. Walcott, who represented the Smithsonian Institution in its membership. An account of Doctor Walcott's many activities in connection with aeronautics and the committee's work is given in another section of this report. At the semiannual meeting of the committee in April, 1927, Dr. Joseph S. Ames, who had served as chairman of the executive committee since 1919, was elected chairman to succeed Doctor Walcott, but the vacancy in the committee's membership caused by Doctor Walcott's death has not been filled.

During the past year as a result of reorganization of Army Air Corps activities, Maj. John F. Curry, formerly chief of the engineering division of the Air Corps, was relieved from membership and Brig. Gen. William E. Gillmore, chief of the newly organized matériel division, was appointed to succeed him.

With the approval of the President, the rules and regulations for the conduct of the work of the National Advisory Committee for Aeronautics were amended during the past year. The effects of the amendments were to create the new positions of vice chairman of the Advisory Committee and vice chairman of the executive committee to be filled by the election of members, and to change the secretaryship from an elective office filled formerly by a member to an appointive office to be filled by a paid official, the appointment to be made by the chairman with the approval of the executive committee. In accordance with these amendments Dr. David W. Taylor was elected vice chairman of the executive committee on June 22, 1927, and by letter ballot circulated under date of June 28, 1927, was also elected vice chairman of the Advisory Committee. On June 22, 1927, Mr. John F. Victory, who had been in the committee's service since its organization in 1915 and had served as assistant secretary since 1917, was appointed secretary of the committee.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 21, 1926, and that held on October 20, 1927.

The organization of the committee at the close of the past year was as follows:

Joseph S. Ames, Ph. D., chairman.  
David W. Taylor, D. Eng., vice chairman.  
George K. Burgess, Sc. D.  
William F. Durand, Ph. D.  
Brig. Gen. William E. Gillmore, United States Army.  
Capt. Emory S. Land, United States Navy.  
Charles F. Marvin, M. E.  
Rear Admiral William A. Moffett, United States Navy.  
Maj. Gen. Mason M. Patrick, United States Army.  
S. W. Stratton, Sc. D.  
Orville Wright, B. S.

### MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held on April 21, 1927, at the committee's headquarters in Washington, and the annual meeting on October 20, 1927, also at the committee's headquarters. At these meetings the general progress in aeronautical research was reviewed and the problems which should be experimentally attacked were discussed. Administrative reports were submitted by the secretary and by the Director of the Office of Aeronautical Intelligence.

At both the annual and the semiannual meetings Doctor Ames, as chairman of the executive committee, presented detailed reports of the research work being conducted by the committee at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., and exhibited charts and photographs showing the methods used and the results obtained in the more important investigations.

At the annual meeting on October 20 the members of the committee accepted an invitation from Admiral Moffett to inspect the aircraft carrier U. S. S. *Saratoga* at the Philadelphia Navy Yard in November, shortly after the carrier is placed in commission. At this meeting also the committee had as its guest Brig. Gen. James E. Fechet, Assistant Chief of the Army Air Corps.

The election of officers was the concluding feature of the annual meeting. The officers of the committee were reelected for the ensuing year, as follows: Chairman, Dr. Joseph S. Ames; vice chairman, Dr. David W. Taylor; chairman executive committee, Dr. Joseph S. Ames.

#### THE EXECUTIVE COMMITTEE

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members, and to include in addition any member of the Advisory Committee not otherwise a member of the executive committee, but resident in or near Washington, and giving his time wholly or chiefly to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.

David W. Taylor, D. Eng., vice chairman.

George K. Burgess, Sc. D.

Brig. Gen. William E. Gillmore, United States Army.

Capt. Emory S. Land, United States Navy.

Charles F. Marvin, M. E.

Rear Admiral William A. Moffett, United States Navy.

Maj. Gen. Mason M. Patrick, United States Army.

S. W. Stratton, Sc. D.

Orville Wright, B. S.

The executive committee, in accordance with the general instructions of the Advisory Committee, exercises the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities.

During the past year the executive committee accepted an invitation from General Patrick and General Gillmore to inspect the facilities and activities of the matériel division of the Army Air Corps in its new location at Wright Field, Dayton, Ohio, and visited the field on October 12, 1927.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the policies and the direction of the activities as approved by the executive committee is vested in the director of aeronautical research, Mr. George W. Lewis. He has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The secretary, Mr. John F. Victory, is ex officio secretary of the executive committee, directs the administrative work of the organization, and exercises general supervision over the expenditures of funds and the employment of personnel.

#### SUBCOMMITTEES

In order to facilitate the conduct of its work the executive committee has organized seven standing subcommittees, as follows:

Governmental relations.

Publications and intelligence.

Personnel, buildings, and equipment.

Aeronautical inventions and designs.

Aerodynamics.

Power plants for aircraft.

Materials for aircraft.

The organization and work of the technical committees on aerodynamics, power plants for aircraft, and materials for aircraft are covered in the reports of those committees appearing in another part of this report, while the work of the committee on aeronautical inventions and designs is included under the subject of the consideration of aeronautical inventions.

During the past year the suggestion was made that the membership of the committees on aerodynamics and power plants for aircraft be enlarged to include representatives of the aircraft industry and of educational institutions offering courses in aeronautical engineering. Such representatives are already included in the membership of the committee on materials for aircraft. This suggestion was given careful consideration by the executive committee and a policy was adopted which will provide for the appointment in the future of special subcommittees organized from time to time under the standing subcommittees and including representatives of the aircraft industry, for the purpose of giving consideration to specific problems, as this plan was deemed more advisable and practicable than to appoint representatives of the industry on the aerodynamics and power plants committees.

A statement of the organization and functions of the administrative committees on governmental relations, publications and intelligence, and personnel, buildings, and equipment follows:

#### COMMITTEE ON GOVERNMENTAL RELATIONS

##### FUNCTIONS

1. Relations of the committee with executive departments and other branches of the Government.
2. Governmental relations with civil agencies.

##### ORGANIZATION

Prof. Charles F. Marvin, chairman.  
Dr. David W. Taylor.  
John F. Victory, secretary.

#### COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

##### FUNCTIONS

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work done in all parts of the world.
2. The encouragement of the study of the subject of aeronautics in institutions of learning.
3. Supervision of the Office of Aeronautical Intelligence.
4. Supervision of the committee's foreign office in Paris.
5. The collection and preparation for publication of the technical reports, technical notes, technical memorandums, and aircraft circulars of the committee.

##### ORGANIZATION

Dr. Joseph S. Ames, chairman.  
Prof. Charles F. Marvin, vice chairman.  
Miss M. M. Muller, secretary.

#### COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

##### FUNCTIONS

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.
2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and offices.
3. To meet from time to time on the call of the chairman, and report its actions and recommendations to the executive committee.
4. To supervise such construction and equipment work as may be authorized by the executive committee.

## ORGANIZATION

Dr. Joseph S. Ames, chairman.  
Dr. David W. Taylor, vice chairman.  
Prof. Charles F. Marvin.  
John F. Victory, secretary.

## QUARTERS FOR COMMITTEE

The headquarters of the National Advisory Committee for Aeronautics are located in the Navy Building, Seventeenth and B Streets NW., Washington, D. C., in close proximity to the Army and Navy air organizations. The committee has recently moved the greater part of its administrative activities from the rear of the third wing, third floor of the Navy Building to larger quarters in the rear of the eighth wing, third floor. This space has been officially assigned for the use of the committee by the Public Buildings Commission. This move was necessitated by the growth in the committee's activities during the past year. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence.

Field stations of the committee are the Langley Memorial Aeronautical Laboratory, at Langley Field, Hampton, Va., and the office of the technical assistant in Europe, located at the American Embassy in Paris.

The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories and shops are utilized, as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

## THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The Langley Memorial Aeronautical Laboratory is operated under the direct control of the committee. It is located at Langley Field, Va., on a plot of ground set aside by the War Department for the committee's use. The laboratory was started in 1916 coincident with the establishment of Langley Field.

The laboratory is organized with four divisions, as follows: Aerodynamics division, power plants division, technical service division, and property and clerical division. The administration of the laboratory is under the immediate direction of an engineer in charge, Henry J. E. Reid, subject to the general supervision of the officers of the committee.

The laboratory consists of seven buildings: A research laboratory building, containing the administrative offices, the headquarters of the aerodynamics and power plants divisions, the technical library, and the photographic laboratory; two aerodynamical laboratories, one containing a wind tunnel of the standard type and the other a variable-density wind tunnel, each laboratory being complete in itself; two engine dynamometer laboratories of a semipermanent type, both equipped to carry on investigations in connection with power plants for aircraft; an airplane hangar with a repair shop and facilities for taking care of airplanes used in flight research; and a service building, containing an instrument laboratory, drafting room, machine and woodworking shops, and storeroom.

During the past year the committee put into operation a novel piece of apparatus known as the propeller research equipment, the construction of which was begun in June, 1925. This equipment is, in effect, a wind tunnel of the Eiffel type with a test chamber of sufficient size to accommodate the fuselage of a full-sized airplane. Full-sized propellers are tested, the propellers being mounted on the engine shaft and operated exactly the same as in free flight. The air stream in which the airplane is mounted is provided by two 1,000-horsepower Diesel engines which operate an eight-bladed propeller 28 feet in diameter. The throat of the test chamber is 20 feet in diameter and tests are conducted at air speeds up to 110 miles per hour. This piece of equipment is the largest wind tunnel in the world.

On August 1, 1927, a fire occurred in the variable-density wind tunnel which destroyed the interior of the structure, including the wind-tunnel cones, balance, propeller, and all instruments. It was necessary to remove entirely every piece of structure and apparatus from the interior of

the wind-tunnel tank, which is 32 feet long and 15 feet in diameter. The fire occurred during a test of an airplane model at 20 atmospheres and was caused by the bursting under pressure of an electric-light bulb which short circuited and caused an arcing that ignited the adjacent wood. Owing to the air circulation in the tunnel of about 50 miles per hour and the great amount of oxygen present in air under pressure of 300 pounds per square inch, the flames spread very rapidly. At the moment the fire was discovered the exhaust valves were opened and all current was cut off, but the equipment in the interior was destroyed because it was impossible to reach the fire inside the tank.

Plans were immediately made for rebuilding the interior of the structure, for making minor repairs to the steel tank housing the tunnel, and for repairing the damage to the building caused primarily by smoke. In rebuilding the tunnel, wood and other inflammable materials will be eliminated and the structure made fireproof.

The variable-density wind tunnel was the most important and valuable single piece of equipment in existence for the purpose of conducting aerodynamical research. It was being fully utilized in the prosecution of fundamental researches, a number of investigations on the program at the time of the fire having been requested by the Army and Navy air organizations.

Recognition by the Government of the necessity of satisfying the increasing demand for new and accurate knowledge on the fundamental problems of flight has made possible the development of the Langley Memorial Aeronautical Laboratory as an efficient research organization numbering 143 employees at the close of the fiscal year 1927. The work of the laboratory is conducted without interference with military operations at the field. In fact, there is a splendid spirit of cooperation on the part of the military authorities who, by their helpfulness in many ways, have aided the committee materially in its work.

#### THE OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the military and naval air services, aircraft manufacturers, educational institutions, and others interested, including the results of research and experimental work conducted in all parts of the world. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed and classified, and brought to the special attention of the subcommittees having cognizance, and to the attention of other interested parties through the medium of public and confidential bulletins. Reports are duplicated where practicable, and distributed upon request. Confidential bulletins and reports are not circulated outside of Government channels.

To handle efficiently the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters at the American Embassy in Paris. It is his duty to visit the government and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and other European countries, and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country, but more especially to secure advance information as to work in progress, and any technical data not prepared in printed form, and which would otherwise not reach this country. John Jay Ide, of New York, has served as the committee's technical assistant in Europe since April, 1921.

The records of the office show that during the past year copies of technical reports were distributed as follows:

Committee and subcommittee members .....	1, 224
Langley Memorial Aeronautical Laboratory .....	2, 209
Paris office of the committee .....	4, 308
Army Air Corps .....	3, 012
Naval Air Service, including Marine Corps .....	3, 817
Manufacturers .....	6, 156
Educational institutions .....	5, 485
Bureau of Standards .....	579
Miscellaneous .....	26, 981

Total distribution .....	55, 636
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Since the promulgation of the Air Navigation Regulations under the air commerce act of 1926 there has been a noticeable increase in requests for technical data. The flight of Colonel Lindbergh and the other transoceanic flights further stimulated interest in aeronautics which has been reflected in the greatly increased demand for the committee's publications. This is evidenced by a comparison of the distribution figures for the past two years. In 1926 the total distribution of technical documents numbered 35,884 and in 1927 it was 55,636, an increase of 55 per cent in one year.

The above figures include the distribution of 25,551 technical reports, 7,197 technical notes, 11,380 technical memorandums, and 5,627 aircraft circulars of the National Advisory Committee for Aeronautics. Part IV of this report presents the titles of the publications issued during the past year whose distribution is included in the foregoing figures. A total of 7,891 written requests for reports were received during the year in addition to innumerable telephone and personal requests, and 31,758 reports were distributed upon request.

#### FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1927, as carried in the independent offices appropriation act approved February 11, 1927, was \$500,000, under which the committee reports expenditures and obligations during the year amounting to \$491,920.80, itemized as follows:

Personal services .....	\$341, 574. 42
Supplies and materials .....	27, 569. 55
Communication service .....	1, 061. 75
Travel expenses .....	11, 595. 61
Transportation of things .....	1, 397. 28
Furnishing of electricity .....	8, 264. 34
Rent of office (Paris) .....	694. 62
Repairs and alterations .....	5, 953. 55
Special investigations and reports .....	37, 000. 00
Equipment .....	56, 809. 68
Expenditures .....	491, 920. 80
Reserve, "Two Per Cent Club" .....	6, 879. 16
Unobligated balance .....	1, 200. 04
Total .....	500, 000. 00

In addition to the above, the committee had a separate appropriation of \$13,000 for printing and binding, of which \$12,995.70 was expended.

## PART II

### GENERAL ACTIVITIES

#### CONSIDERATION OF AERONAUTICAL INVENTIONS

In its twelfth annual report for the year 1926 the committee presented a report on the organization of the Aeronautical Patents and Design Board, consisting of the three Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce. The report also presented an outline of the procedure followed by the committee in considering inventions and designs submitted to it. Under that procedure the committee has conducted the necessary correspondence with inventors to disclose clearly the ideas they have had in mind and made reports to the Aeronautical Patents and Designs Board, describing the inventions, analyzing the principles involved, and making definite recommendations. The number of designs submitted required frequent meetings of the board to consider the reports and recommendations of the National Advisory Committee for Aeronautics. The procedure under the law required careful consideration by the board of each report on a design submitted by the committee to the board, and the board had the sole responsibility for the final disposition of each invention or design submitted.

The act of Congress approved March 3, 1927, worked a change in the above procedure, for it amended the act creating the Patents and Design Board so as to limit the jurisdiction of the board in making awards to the consideration of those cases in which the National Advisory Committee for Aeronautics made favorable recommendations. One effect of this change was to make the National Advisory Committee a responsible agency of the Government for the final disapproval of the vast majority of applications for awards for aeronautical inventions or designs submitted to the Government, leaving to the Patents and Design Board the final decision only in those cases which received the favorable recommendation of the committee. Another effect of the amended legislation incident to relieving the board of the burden of considering cases unfavorably recommended by the committee was the loss by the inventor of his opportunity for a personal hearing before the board unless his invention were favorably recommended by the committee.

In view of the changed circumstances resulting from the legislation of March 3, 1927, the National Advisory Committee for Aeronautics on March 18, 1927, created a subcommittee on aeronautical inventions and designs, the organization and rules of procedure of which are as follows:

#### ORGANIZATION

Dr. D. W. Taylor, chairman.  
Dr. George K. Burgess, vice chairman.  
Capt. E. S. Land, United States Navy.  
Prof. Charles F. Marvin.  
Mr. J. F. Victory, secretary.

#### RULES OF PROCEDURE

1. The chairman will preside at meetings of the committee and will carry into effect the actions of the committee. In his absence the vice chairman will preside. Three members will constitute a quorum.
2. The secretary will issue notices of meetings, prepare an order of business for each meeting, arrange for the appearance of parties to be heard, record the minutes and transactions of the committee, and perform such other duties as may be assigned.
3. All inventions and designs shall be submitted in writing and be accompanied by descriptive matter sufficiently clear to present the idea.

4. The director of aeronautical research is designated to consider and dispose of inventions and designs submitted, and to conduct with inventors, with the Patents and Design Board, and with others, all correspondence up to the point where a case is taken up specifically for consideration by the committee.

5. The committee will take up specifically for consideration only those inventions or designs that have been recommended to it in writing by a member of the National Advisory Committee for Aeronautics not a member of the committee on aeronautical inventions and designs, or by the director of aeronautical research, and in any case only after preliminary consideration of the same by the director of aeronautical research. In such cases hearings will be granted upon request of the parties making such submissions.

6. The committee may, in its discretion, hear others in support or in denial of the claims of an inventor, and may obtain any information available bearing on the subject matter under consideration.

7. The proceedings before the committee will be informal.

8. The committee will not undertake to determine the validity of a patent nor will it consider claims for alleged infringement of a patent.

9. Inventions and designs will be considered by the committee only as to their technical merit, irrespective of whether they are patented or unpatented; but evidence of lack of novelty may be taken into consideration.

10. The findings and recommendations of the committee on all claims considered by it will be transmitted direct to the Patents and Design Board; provided that the committee may, in its discretion, refer any claim or question in connection therewith to the executive committee of the National Advisory Committee for Aeronautics.

In addition to the foregoing rules of procedure, the following general principles have been agreed upon:

(a) That favorable recommendations to the Patents and Design Board will be made only after consideration by the committee on aeronautical inventions and designs.

The effect of this is to limit the director of aeronautical research to the submission of unfavorable recommendations to the Patents and Design Board.

(b) That on favorable recommendation to the inventions committee from the director of aeronautical research the committee will not make an adverse report without giving the inventor an opportunity to be heard.

The first meeting of the Aeronautical Patents and Design Board was held in the conference room of the National Advisory Committee for Aeronautics on October 12, 1926. In the interests of economy and efficiency the board's records have been maintained by the committee but kept separate and distinct from the committee's records. During the first 12 months of the operation of the Aeronautical Patents and Design Board, approximately 1,000 inventions or designs were received by the committee, about one-half of which had been originally submitted by the applicants either directly or indirectly for the attention of the board. Of the number submitted for the attention of the board (approximately 500) the committee has submitted to the board reports and recommendations in 450 cases, which included favorable recommendations in only 3 cases. The remaining 500 cases submitted direct for the committee's consideration have been disposed of by direct correspondence with the inventors and no design included in this number was worthy of favorable recommendation to the board.

The volume of inventions and designs submitted has been increasing steadily since the summer of 1927, and the burden of this work has required additions to the engineering and clerical staffs of the committee.

Under the present procedure careful consideration is given to all inventions and designs submitted. The Aeronautical Patents and Design Board and the National Advisory Committee for Aeronautics are working in harmony and the burden of considering large numbers of inventions is placed so as to reduce the demands on the time of the members of the subcommittee on aeronautical inventions and designs and of the members of the Aeronautical Patents and Design Board to the consideration of submissions which have received competent preliminary examination and are deemed worthy of further consideration.

### RELATIONS WITH THE AIRCRAFT INDUSTRY

In order to give to the manufacturers and operators of aircraft an opportunity to become more closely acquainted with the facilities of the committee's laboratory for the conduct of aeronautical research and to encourage the representatives of the industry to present to the committee research problems arising out of the development of civil and commercial aeronautics, with a view to the possible incorporation of such problems in the committee's research program, the committee in 1926 inaugurated the policy of holding annual conferences between its representatives and representatives of the industry.

In accordance with this policy the second general conference between representatives of the industry and of this committee was held at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., on May 24, 1927. In addition to the aircraft manufacturers and operators, aeronautical trade journals and educational institutions engaged in the teaching of aeronautical engineering were invited to send representatives to this conference. The National Advisory Committee for Aeronautics was represented by its subcommittees on aerodynamics and materials for aircraft and by members of its technical staff. Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics and also at that time chairman of the subcommittee on aerodynamics, presided.

At a preliminary meeting held in the morning the functions and work of the committee were briefly outlined, following which the representatives of the industry were conducted on a tour of inspection of the laboratory and the investigations under way were explained. This occasion marked the formal opening of the committee's new propeller research equipment. In the afternoon the conference proper convened and after a brief statement by the chairman as to the purpose of the meeting, there was general discussion of the problems of commercial aviation in which the representatives of the industry participated. Among the problems which were mentioned as of importance to commercial aviation were the various factors relating to the comfort and convenience of passengers in airplanes and particularly the elimination of noise; the question of controllability at low speeds; and the effect of protuberances on an otherwise faired stream-line body. One of the problems suggested, the study of the effect of cowlings and fuselage shape on the resistance and cooling characteristics of air-cooled engines, was promptly incorporated in the committee's research program.

Following the conference proper, the subcommittee on materials for aircraft met in joint session with the other members of the conference, Dr. George K. Burgess, Director of the Bureau of Standards and chairman of the materials subcommittee, presiding. Doctor Burgess made a brief statement pointing out the importance to aeronautics of the light alloys of aluminum, particularly duralumin, and referring to the difficulties involved in the use of duralumin. Mr. E. H. Dix, jr., of the Aluminum Co. of America, presented a paper with slides, describing "Alclad," a newly developed corrosion-resistant aluminum product. This was followed by a general discussion of the problems in connection with aircraft materials, particularly aluminum alloys.

### THE COMMITTEE'S RESEARCH PROGRAM IN RELATION TO NONMILITARY AIRCRAFT

At the semiannual meeting of the entire membership of the National Advisory Committee for Aeronautics held on April 21, 1927, Doctor Ames, the chairman, invited attention to the following extract from a report of the Committee of Experts on Civil Aviation to the Preparatory Commission for the Disarmament Conference assembled at Geneva:

The committee desires to state at the outset that civil aviation must in itself be regarded as one of the most important factors of civilization, and it is desirable that its free development should not be hampered by any consideration unconnected with the importance which that development possesses from the point of view of scientific, economic, and social progress and of the improvement of communications between peoples. The committee, regarding the question in this light, unanimously agreed that its examination of the subject should be based on the following principle:

In any limitation of air armaments it is essential to avoid hampering the development of civil aviation.

The chairman also invited attention to a recommendation of the Committee of Experts on Civil Aviation that international agreements proposing to limit military and civil aviation be made only for short terms.

Although the Geneva Conference adjourned in disagreement, it is believed that the principle involved in the above quoted report reflects accurately the state of enlightened international opinion regarding the development of civil aviation.

At the meeting referred to, the chairman next outlined the growth in aeronautical education in American universities during the past year which was largely made possible by gifts from the Daniel Guggenheim Fund for the Promotion of Aeronautics. He invited attention to the enlargement of aeronautical facilities at the Massachusetts Institute of Technology, New York University, the University of Michigan, Stanford University, and the California Institute of Technology. Numerous other colleges and institutions of learning had communicated with the committee requesting information as to equipment, such as small wind tunnels, which they contemplated incorporating as part of their experimental equipment for their regular engineering courses. The committee not only furnished the information requested but also gave advice in regard to the equipment and supplies necessary to make it possible for such institutions to offer elective courses to engineering seniors, and where practicable to incorporate aeronautical problems in engineering courses. The object was to acquaint engineering students generally with the fundamentals of aeronautics in much the same manner as they are now made acquainted in regular engineering courses with the fundamentals of hydrodynamics and hydraulics.

The chairman then noted the increased production of civil and commercial airplanes in America and observed that with the evidence of growth of commercial and private operation of aircraft it seems that the committee's research program may properly be so formulated as to include the fundamental problems presented by the development of civil and commercial aviation. Whereupon the following resolution was adopted:

*Resolved*, That in view of the enactment of the air commerce act of 1926 for the encouragement and regulation of commercial aeronautics, and of the increasing activity in the manufacture and operation of civil and commercial types of airplanes, the National Advisory Committee for Aeronautics directs the attention of its subcommittees to the desirability of considering those fundamental problems the solution of which in their judgment will tend to increase the safety and decrease the cost of construction and operation of such aircraft, and requests that the subcommittees submit recommendations to the executive committee for the approval of such research authorizations as in their judgment will serve best to solve these fundamental problems.

In accordance with the foregoing resolution, consideration of this problem was given by the subcommittees on aerodynamics, power plants for aircraft, and materials for aircraft, and a number of research authorizations were recommended to the executive committee which are now being carried into effect.

#### THE DANIEL GUGGENHEIM FUND FOR THE PROMOTION OF AERONAUTICS

The committee is pleased to note that the activities of the Daniel Guggenheim Fund for the Promotion of Aeronautics have been carefully planned so as to produce a maximum of immediately practical and substantial assistance to aviation in its commercial, industrial, and scientific aspects, while at the same time avoiding duplication with existing agencies, governmental and private.

The Daniel Guggenheim Fund for the Promotion of Aeronautics was established by Mr. Daniel Guggenheim on January 16, 1926. Its general purposes may be broadly defined as follows:

1. To promote aeronautical education both in higher institutions of learning and among the general public.
2. To assist in the extension of fundamental aeronautical science.
3. To assist in the development of commercial aircraft and aircraft equipment.
4. To further the application of aircraft in business, industry, and other economic and social activities of the Nation.

The major activities of the fund during the past year included the making of a study of the educational institutions of the country and especially those which had established courses in aeronautics, with a view to providing in different sections of the country adequately equipped schools giving courses in aeronautical engineering. As a result of this study grants of money were made by the fund to two California institutions, namely, Stanford University and the California Institute of Technology, at Pasadena; in the East funds were granted to the Massachusetts Institute of Technology, at Cambridge, and to New York University, in New York City; and in the Middle West funds were granted to the University of Michigan, at Ann Arbor.

The trustees of the fund announced that a primary aim of the fund would be the promotion of safety in flying. To this end the fund provided for a safe aircraft competition which for the first time in the history of American aviation caused concerted efforts to be made by manufacturers and designers in various countries to make safer airplanes. The rules and regulations of the competition are intended to encourage the design and construction of aircraft in which those characteristics which are considered most essential for safety shall be developed to a higher degree than exists in present types of aircraft.

The aerial tour of the United States by Col. Charles A. Lindbergh during the fall of 1927 was made possible by the Guggenheim Fund. In this tour Colonel Lindbergh visited every State in the Union and by public addresses before great numbers of the American people brought home to the municipalities a realization of the great need for providing municipal airports.

Among the other activities of the fund was the calling of a conference of representatives of universities engaged in aeronautical educational work. The fund was also active in studying the problems of aerology, fog flying, and navigational instruments.

#### CONFERENCE OF REPRESENTATIVES OF EDUCATIONAL INSTITUTIONS ACTIVELY ENGAGED IN AERONAUTICAL EDUCATION

The Daniel Guggenheim Fund for the Promotion of Aeronautics called a conference of representatives of educational institutions actively engaged in aeronautical educational work for the purpose of interchanging ideas relative to educational methods, coordinating research work, and developing specialized courses in aeronautical education. The following educational institutions were represented:

- Massachusetts Institute of Technology.
- New York University.
- Stanford University.
- California Institute of Technology.
- University of Michigan.
- University of Washington.

The matériel division of the Army Air Corps and the National Advisory Committee for Aeronautics were also represented.

Dr. William F. Durand, a member of the Daniel Guggenheim Fund for the Promotion of Aeronautics and a member and past chairman of the National Advisory Committee for Aeronautics, acted as chairman of the conference. Upon the request of the fund the committee gave the use of its conference room for the meetings, which were held on December 10 and 11, 1926. The conference was financed by the Guggenheim Fund.

The conference considered in particular the scope and the character of the courses of instruction in the various educational institutions and the possibility of developing specialized courses in aeronautics so that students wishing to specialize in any particular branch would have an opportunity of obtaining this instruction in one of the large universities.

The subject of aeronautical research was given careful consideration and the various institutions were requested to prepare and submit programs of aeronautical research to the Daniel Guggenheim Fund for the Promotion of Aeronautics.

The programs were later submitted to the National Advisory Committee for Aeronautics and brought to the attention of its standing technical subcommittees which have general cognizance of aeronautical research in the respective spheres of aerodynamics, power plants, and materials for aircraft. The programs referred to may be found under the report of the committee on aerodynamics.

## COOPERATION OF ARMY AND NAVY

Through the personal contact of the heads of the Army and Navy air organizations serving on the main committee and the frequent personal contact on the subcommittees of their chief subordinates who have to do with technical matters in aeronautics, there has been accomplished in fact not only a coordination of aeronautical research, which is the major function of the committee, but also a coordination of experimental engineering activities of the services and an exchange of first-hand information, comment, and suggestions that have had beneficial effects in both services. The needs of each service in the field of aeronautical research are discussed and agreements invariably reached that promote the public interests. The cordial relations that usually follow from frequent personal contact are supplemented by the technical information service of the committee's Office of Aeronautical Intelligence, which makes available the latest scientific data and technical information secured from all parts of the world. Although there is a healthy rivalry between the Army and Navy air organizations, there is at the same time a spirit of cooperation and a mutual understanding of each other's problems that serve to prevent unnecessary duplication in technical developments in aeronautics.

Much of the fundamental research work of the committee has grown out of requests received from the Army and Navy for the study by the committee of particular problems encountered in the services, and in connection with this work the committee desires to give special recognition to the splendid spirit of cooperation of the two services with the committee. Each service has placed at the disposal of the committee airplanes and engines required for research purposes, and has otherwise aided in every practical way in the conduct of scientific investigations by the committee. Without this cooperation the committee could not have prosecuted successfully many of its investigations that have made for progress in aircraft development. The committee desires especially to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located, and by the naval authorities at the Hampton Roads Naval Air Station.

## INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND THE NAVY

As a rule research programs covering fundamental problems demanding solution are prepared by the technical subcommittees and recommended to the executive committee for approval. These programs supply the problems for investigation by the Langley Memorial Aeronautical Laboratory. When, however, the Army Air Corps or the Naval Bureau of Aeronautics desires special investigations to be undertaken by the committee, such investigations, upon approval by the executive committee, are added to the current research programs.

The investigations thus under conduct by the committee during the past year for the Army and the Navy may be outlined as follows:

## FOR THE AIR CORPS OF THE ARMY

- Investigation of the flat spin of the Douglas O-2 airplane.
- Full-scale investigation of different wings on the Sperry messenger airplane.
- Investigation of the behavior of an airplane in landing and in taking off.
- Investigation of pressure distribution and accelerations in pursuit type airplane.
- Acceleration readings on the PW-9 airplane.

## FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

- Investigation of pressure distribution on vertical tail surfaces fitted with balanced rudders.
- Investigation of methods of improving wing characteristics by control of the boundary layer.
- Development of a solid-injection type of aeronautical engine.
- Investigation of method of improvement in range of vision of pilot in an airplane.
- Investigation of maximum tail loads in dives.
- Investigation of the effect of fineness ratio on airship models.
- Design of accelerometers for determination of accelerations in catapulting.

Investigation of the forces on seaplane floats under landing conditions.  
 Investigation of water pressure distribution on seaplane hulls.  
 Study of design factors for metal propellers.  
 Investigation of application of compression ignition operation to air-cooled engine cylinders.  
 Investigation of flight path characteristics.  
 Effect of varying the aspect ratio and area of wings on performance of fighter airplane with supercharged air-cooled engine.  
 Investigation of aerodynamic loads on the U. S. S. *Los Angeles*.  
 Investigation of autorotation.  
 Investigation of spoiler aileron control.  
 Development of aircraft engine supercharger.  
 Investigation of performance of five propellers in flight.  
 Effect of various forms of cowling on performance and engine operation of fighter airplane with supercharged air-cooled engine.

#### USE OF NONGOVERNMENTAL AGENCIES

The various problems on the committee's approved research programs are as a rule assigned to governmental agencies for study and investigation. In cases where the proper study of a problem requires the use of facilities not available in any governmental establishment, or requires the talents of men outside the Government service, the committee contracts directly with the institution or individual best equipped for the study of each such problem to prepare a special report on the subject. Such special reports are published the same as other technical reports of the committee. In this way the committee makes effective use of the facilities of educational institutions and the services of specialists in the scientific study of the problems of flight.

#### COOPERATION WITH BRITISH AERONAUTICAL RESEARCH COMMITTEE

The cordial relations which have existed for a number of years between this committee and the Aeronautical Research Committee of Great Britain have been continued during the past year. In the summer of 1927 Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics, visited Europe to observe recent progress and developments in aeronautical research in England and France, and while in England conferred with the Aeronautical Research Committee, representatives of the Air Ministry, and members of the staff of the National Physical Laboratory, and viewed the work in progress at the British laboratories. Many of the important problems of aeronautical research at the present time were discussed, and there was a free interchange of ideas. One of the points tentatively agreed upon was the exchange between the two committees of special instruments for use in flight research, in order that comparative tests on the same instruments might be made at different laboratories.

The program of comparative research for the standardization of wind tunnels carried on for the past several years by the two committees has been continued. This program included tests by this committee of models of airships, airplanes, and wing sections which had first been tested by the British committee. The results of tests in this committee's variable-density wind tunnel at Langley Field were of particular value in the subject of wind-tunnel standardization, and also in the study of scale effect on models. During the past year an agreement was reached between the two committees which provided for the publication separately by each committee as soon as practicable, of the results of the tests conducted by that committee, the comparative results from the two countries to be published at a later date. In accordance with this policy, papers covering the tests in this country of airship and airplane models will be published in the near future.

During the past year tests conducted in the variable-density wind tunnel at Langley Field as part of this program have been completed on three British airplane models with different wing sections. The models tested were a Bristol fighter with R. A. F. 15 wing section, a BE-2E with R. A. F. 19 wing section, and a Bristol fighter with R. A. F. 30 wing section. The results

of the tests on these models were forwarded to the British committee for analysis. The British committee is considering the question of constructing in England a variable-density wind tunnel similar in type to that at Langley Field for the study of scale effect.

On suggestion of the Aeronautical Research Committee, this committee last year forwarded to England for comparative tests a metal model propeller which had previously been tested in the open-type wind tunnel at Stanford University. This model is now undergoing test in the closed-type wind tunnel at the National Physical Laboratory.

#### EXHIBIT AT THE NATIONAL SESQUICENTENNIAL EXPOSITION

During the summer and fall of 1926 the committee maintained an exhibit in the Transportation Building of the National Sesquicentennial Exposition in Philadelphia, which exhibit was described in the committee's annual report for the year 1926. That exhibit proved to be very popular with all classes of visitors. Working models on exhibition depicted the methods employed in the conduct of scientific research in aeronautics. The exhibit closed on November 30, 1926. Shortly thereafter the jury of awards conferred a "grand prize certificate of award" upon the National Advisory Committee for Aeronautics for its "collective exhibit of working models used in scientific research on the fundamental problems of flight." The jury of awards also conferred a gold medal upon the National Advisory Committee for Aeronautics for its "exhibit of automatic recording instruments used in aeronautical research."

The diplomas of award have been framed and displayed at the committee's headquarters.

Mr. George W. Lewis, director of aeronautical research, was the contact officer between the committee and the Sesquicentennial Exposition Commission, and the committee's exhibit was installed under the personal supervision of Mr. John F. Victory, at that time assistant secretary of the committee.

#### INTERNATIONAL CONGRESS ON AERIAL NAVIGATION, ROME

In June, 1927, the Department of State requested an expression of opinion from the committee in regard to an invitation of the Italian Government that the United States be officially represented at an International Congress on Aerial Navigation to be held in Rome in October, 1927. In reply the committee offered the services of its technical assistant in Europe, Mr. John J. Ide, as a representative of the United States if the Department of State should so desire. In accordance with the committee's suggestion, and with the approval of the President, the Department of State designated Mr. Ide as one of the delegates on the part of the United States to the International Congress, which opened in Rome on October 24, 1927.

#### THE AIR MAIL SERVICE

On July 1, 1927, the air mail service officially passed from governmental operation into the hands of private carriers acting under contracts with the Post Office Department. The passing of the air mail service as a governmental activity closes a most interesting chapter in the history of aeronautical development and opens another, the significance of which it is difficult to visualize.

The air mail service was inaugurated in February, 1918, on the New York to Washington route. The National Advisory Committee for Aeronautics had been greatly interested in the project as discussions of the practicability and desirability of an air mail service had begun in committee sessions as early as December of 1916, and the committee had invited representatives of the Post Office Department to attend meetings from time to time for the purpose of encouraging the department to inaugurate such a service. The committee was largely responsible for the selection of the relatively safe route between New York and Washington for the first experiment. Gradually the air mail service was extended to connect the east and west coasts and also to serve other localities off the main transcontinental airway.

In December, 1922, questions of broad policy arose regarding the future of the air mail service and its fundamental purposes. In response to a request from President Harding the National Advisory Committee for Aeronautics made a study of the problem and submitted

a report dealing with the fundamental purposes of the air mail service, its accomplishments and what remained to be accomplished, and presenting a comparison of an operating with a development program and certain recommendations. In that report the committee stated that "The fundamental purpose of the air mail service is to demonstrate the safety, reliability, and practicability of air transportation of the mails, and incidentally of air transportation in general," and added that it should "Develop a reliable 36-hour service between New York and San Francisco, and make that service self-supporting by creating the necessary demand for it and charging a rate between ordinary postage rates and night-letter telegraph rates." The committee reported further that "In the present undeveloped state of the art, it would be wholly impracticable to operate an air mail service by contract."

The committee expressed the opinion that the most important objects remaining to be accomplished were to "demonstrate that night flying is practicable over a regular route and schedule," and to "bring about the development of an efficient type of airplane for this special purpose." The committee's report closed with recommendations that the air mail service be continued under the Post Office Department until it had—

- (1) Demonstrated the practicability of night flying in the mail service and actually established a regular service between New York and San Francisco in 36 hours or less;
- (2) Met the popular demand for a fast transcontinental service and made such service self-supporting by means of appropriate rates;
- (3) Demonstrated the exact cost and economic value of air transportation, using the most appropriate equipment, including airplanes specially designed for efficient performance.

The committee further recommended that "when the above program is once accomplished the further application of aircraft to the carrying of mail be effected by contracts with private enterprise."

The policy recommended by the National Advisory Committee for Aeronautics was approved by President Harding. How well it has been carried into effect is attested best by the record of progress of the air mail service. There has been no more valuable experiment in aeronautics and certainly none that contributed more directly to the demonstration of the practical value of air transportation and to the advancement of aeronautics generally.

Under the fundamental policy of the Post Office Department mail is bound to be carried eventually by the fastest means available, and the Post Office Department deserves recognition by the people of the United States of the important part it has played in demonstrating the practical use of aircraft in the transportation of the mail. The economic value of air transportation of the mails now that the service is operated by private contractors will continue to be tested and demonstrated until the air mail service is extended to serve communities in all parts of the country.

## PART III

### REPORTS OF TECHNICAL COMMITTEES

#### REPORT OF COMMITTEE ON AERODYNAMICS

##### ORGANIZATION

The committee on aerodynamics is at present composed of the following members:

Dr. David W. Taylor, chairman.  
Capt. H. C. Richardson, United States Navy, vice chairman.  
Dr. L. J. Briggs, Bureau of Standards.  
Lieut. Ernest W. Dichman, United States Army, matériel division, Air Corps, Wright Field.  
Lieut. W. S. Diehl, United States Navy.  
Prof. Alexander Klemin, Department of Commerce.  
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
Maj. Leslie MacDill, United States Army, matériel division, Air Corps, Wright Field.  
Prof. Charles F. Marvin, Weather Bureau.  
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.  
Dr. A. F. Zahm, construction department, Washington Navy Yard.

During the past year, Dr. Joseph S. Ames, who had for several years served as chairman of the committee on aerodynamics, submitted his resignation because of the additional demands on his time entailed by his election as chairman of the National Advisory Committee for Aeronautics. Dr. David W. Taylor was appointed to succeed him. The executive committee, in accepting Doctor Ames' resignation, recorded an expression of its sincere appreciation of the invaluable service rendered by Doctor Ames, who had presided at sessions of the committee on aerodynamics for over eight years.

##### FUNCTIONS

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments, in progress or proposed.
4. To direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on aerodynamics, by reason of the representation of the various organizations interested in aeronautics, is in close contact with all aerodynamical work being carried out in the United States. In this way the current work of each organization is made known to all, duplication of effort being thus prevented. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduct of aerodynamic research. The committee keeps the research workers in this country supplied with information on European progress in aerodynamics by means of a foreign representative who is in close touch with aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The committee on aerodynamics has direct control of the aerodynamical research conducted at Langley Field, certain propeller research conducted at Stanford University under the supervision of Dr. W. F. Durand, and a number of special investigations conducted at the Bureau of Standards. The aerodynamical investigations undertaken at the Washington Navy Yard, the matériel division of the Army Air Corps at Wright Field, and the Bureau of Standards are reported to the committee on aerodynamics.

#### SUBCOMMITTEE ON AIRSHIPS

In order that the committee on aerodynamics may be kept in closer touch with the latest developments in the field of airship design and construction, and that research on lighter-than-air craft may be fostered and encouraged to a greater extent, a subcommittee on airships was organized in September, 1927, under the committee on aerodynamics, with the following membership:

Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics, chairman.  
 Starr Truscott, National Advisory Committee for Aeronautics, vice chairman.  
 Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.  
 Commander Garland Fulton, United States Navy.  
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
 Capt. Edgar P. Sorenson, United States Army, matériel division, Air Corps, Wright Field.  
 R. H. Upson, Aircraft Development Corporation.

The initial meeting of this subcommittee was held during October, at which recent investigations in the field of lighter-than-air research were surveyed and problems for future investigation considered. Subsequently Captain Sorenson was relieved and Capt. William B. Mayer was appointed as a representative of the Army Air Corps.

#### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

**ATMOSPHERIC WIND TUNNEL.**—*Pressure distribution.*—In continuation of tests requested by the Army Air Corps a half-span model of the biplane wing system of the Boeing pursuit airplane has been tested to obtain the distribution of pressure over each wing. The wings were also tested individually as monoplanes. In accordance with the practice now in effect in this tunnel, these wings were tested over a large range of angles of attack. The results showed that the air-flow modification mutually produced by the two wings in proximity to one another is confined chiefly to their adjacent surfaces. Reasons hitherto advanced for the difference between the air forces on monoplanes and biplanes at large angles of attack were confirmed by these tests.

*Autorotation.*—As a result of experience gained in spinning tests made on behalf of the Army and Navy air services, a study of the general subject of autorotation has been continued throughout the year.

A light airplane model, proportionate in weight as well as in size, was mounted in the tunnel free to pitch and to roll about its center of gravity. This model was found to be capable of autorotation as a monoplane up to  $26^\circ$  angle of attack, and as a biplane up to  $80^\circ$ . Four rectangular wing models (a biplane and three monoplanes) were then tested for autorotational characteristics. From these tests it was concluded that in flight a monoplane will not "flat spin," whereas an unstaggered biplane has inherent "flat-spinning" tendencies. These tests led to a general study of the unstable conditions occurring in the "stalled" flight of the orthodox airplane.

The impossibility of calculating accurately the autorotational characteristics of wing systems by the use of the conventional "strip method" led to pressure distribution tests on one of the wings used in the above-mentioned autorotation experiments. An analysis of these results is now being made with a view to improving the accuracy of autorotation calculations.

Tests are in progress to determine the autorotational characteristics of the various wing arrangements employed in modern airplanes. Every effort is being made to produce a non-spinning wing for the purpose of reducing the hazards of "stalled" flight.

*Boundary layer control.*—The possibility of important gains in airplane efficiency and performance by proper control of the so-called boundary layer has been investigated at this laboratory at the request of the Bureau of Aeronautics, Navy Department. Owing to the retardation of the air flow at the surface of a wing, as the angle of attack is increased the smooth flow over the upper surface ultimately breaks down completely and separates from it, thereby causing a loss of lift. By accelerating or by removing the "dead" air in this region of retarded flow (boundary layer) the breakdown may be delayed until greater angles of attack are reached, thus making available a greater lift.

A large number of pressure distribution tests have been made on a U. S. A. 27 airfoil fitted with various types and combinations of slots through which air has been blown or sucked for the purpose of controlling the boundary layer. The results of these tests have shown that the power required by an airplane may be reduced by the use of suitable slot arrangements in the wings. Removal of the boundary layer by suction has proved to be more economical than the acceleration of the layer by pressure.

The U. S. A. 27 airfoil was found to be unsatisfactory for this work by reason of its relatively sharp nose and consequently high nose pressures. The investigation is now being continued on a thick round-nosed airfoil having a theoretically derived profile of the Joukowski type. Preliminary tests on this airfoil have shown satisfactory nose pressures.

*Wind-tunnel apparatus.*—A new apparatus for pressure distribution tests has been placed in service during the past year. It comprises a wood separation plane, a 115-tube photographic manometer, and a wing support permitting a 360° angle-of-attack range.

Several minor changes have been made in the force-test wire balance, resulting in more uniform operation and reduction of the personal factor in force testing.

*Miscellaneous.*—A mathematical analysis has been made of the problem of balancing flying models of airplanes for spinning tests. The study included the derivation of a method for giving the model the various known weight distributions for the purpose of determining their effect upon spinning.

At the inception of the recent series of long-distance flights a study was made of take-off conditions for heavily loaded airplanes. It has been suggested that the fact that an airplane can be made to take-off, even when so heavily loaded that it can not climb higher than the span of its wings, may account for several of the recent crashes.

A new study has been made of data obtained in this tunnel some years ago on an oscillating wing. As a result, it has been found that the lift of a wing while pitching is, in general, less than the lift of a stationary wing for the same angle of attack. A qualitative explanation of the phenomenon of the pitching airfoil has been derived from aerodynamic theory.

*VARIABLE-DENSITY WIND TUNNEL.*—This wind tunnel has been in continuous operation throughout the past year, during which three major researches and several minor ones have been conducted.

*Three British airplane models.*—In cooperation with the British Aeronautical Research Committee, an investigation was conducted in the variable-density wind tunnel on a series of airplane models which had been tested at the National Physical Laboratory and at the Royal Aircraft Establishment. Full-scale experiments had been made on the airplanes at Farnborough. The research consisted of tests to determine the scale effect on models of three British airplanes (BE-2E with R. A. F. 19 wings, Bristol fighter with R. A. F. 15 wings, and Bristol fighter with R. A. F. 30 wings). The scale effect on the maximum lift coefficient was the important item. Comparison was made with full-scale flight tests made in England on the original airplanes and a remarkably good agreement was obtained. A report has been written covering these tests.

*R. A. F. 19 airfoil section, scale effect.*—Three airfoil models of different sizes, having the R. A. F. 19 section and an aspect ratio of 6, were tested through the complete range of Reynolds Number of the tunnel to determine the effect of the size of the model and the density of the fluid on the aerodynamic characteristics of this section. The scale effect on the maximum lift coefficient agreed with previous data obtained on a model airplane using this section. The

effect of the size of the model in relation to the Reynolds Number was in accordance with the theory. This research is to be continued on another section and with variation of the velocity as well as the size of the model and the density.

*N. A. C. A.—M6 airfoil with flap and ailerons.*—At the first annual conference between the aircraft manufacturers and the committee on aerodynamics it was suggested that an investigation be undertaken to ascertain the effect of a flap and of ailerons at high angles of attack and at a Reynolds Number equivalent to full scale. A large model of the N. A. C. A.—M6 airfoil section fitted with a flap and ailerons, 20 per cent of the chord in width, was therefore tested at a density of 20 atmospheres up to high angles of attack for various settings of the flap and of the ailerons. Large changes in the values of the aerodynamic characteristics were obtained with changes in the flap setting. At a downward setting of  $25^\circ$ , a maximum lift coefficient of 1.71 was obtained. It is indicated from these tests that such a system may be used for decreasing the wing area of an airplane, or its landing speed. The travel of the center of pressure for the various conditions was determined. A report on these tests has been published.

*Goodyear-Zeppelin airship tests.*—At the request of the Navy Department, eight models of airships of different length-diameter ratios, of Goodyear-Zeppelin design, have been tested by means of the main balance through the full range of Reynolds Number obtainable, the tests including the determination of the lift, drag, and pitching moment at various angles of pitch. Further tests were then made by means of a more accurate drag balance to determine the resistance at zero pitch. The resistance of all the models showed a slight decrease in value as the scale was increased and it was found that on a basis of volume, a model of length-diameter ratio of near 6 has the least resistance coefficient. A comparison of the characteristics of these models was made with those of other models recently tested in this tunnel. A report has been written covering this investigation.

*Miscellaneous.*—Replicas of the long and short airship models constructed at the British National Physical Laboratory and used for wind-tunnel standardization research have been tested in this tunnel. A technical note has been published covering the results and their relation to previous data on these models.

Three N. A. C. A.—M6 biplane cellules of different staggers were tested up to an angle of attack of  $48^\circ$  to determine their characteristics at high angles and the effect of scale. A report has been written on the results of these tests.

A report covering tests mentioned in last year's report on the Sperry messenger airplane model equipped with six different sets of wings has been written. Comparison with similar tests in the committee's atmospheric wind tunnel was made.

An investigation of the relative thrusts obtainable from a reaction jet by the use of suitable augmentors of the Venturi type was made, the Melot system being used. A report has been drafted on this investigation.

A dynamic pressure survey by means of a minute Pitot tube was made very close to the tunnel wall to obtain data on the change in velocity head near the wall and further information on the "boundary layer." This work is covered in a report on an analysis of tunnel-wall effect.

**PROPELLER RESEARCH EQUIPMENT.**—The committee has realized for some time the need for an accurate means of making aerodynamic measurements on full-scale aircraft propellers. Tests on model propellers in wind tunnels are not entirely satisfactory because the deflection of the model is different from that of its full-sized propeller. This introduces a rather large error in some cases. The difference in scale effect and tip speed between the model and full scale propeller is also a cause of error. Full-scale flight tests have, of course, the correct conditions, but at the present time they can not be made with sufficient accuracy to be relied upon.

Two years ago the design and construction of a propeller research equipment to fill this need for full-scale tests was started by the committee. It has been completed during the past fiscal year and testing operations are now under way. This equipment consists of a wind tunnel of the open-jet type large enough to permit the mounting of a full-sized airplane fuselage with its engine and propeller. The diameter of the jet is 20 feet and an air velocity of 110

miles per hour has been obtained by means of a propeller fan 28 feet in diameter having eight cast aluminum alloy blades. The power to turn this propeller is furnished by two 1,000-horsepower Diesel engines.

The airplane under test is mounted on a balance which supports it in the center of the air stream. By means of this balance thrust, drag, lift, pitching moment, and rolling moment can be measured. There are also a special test fuselage, having a built-in dynamometer scale for measuring engine and propeller torque, and a device for measuring the deflection of propeller blades in operation.

This equipment makes it possible for the first time to make aerodynamic tests with laboratory accuracy on full-scale aircraft propellers. In addition tests may be made on fuselages, engine cowlings, cooling systems, landing gears, tail surfaces, and other airplane parts.

*Air-flow survey.*—A survey has been made of the velocity of the air through the test chamber, with gratifying results. It was found that the velocity was very uniform throughout a cross section of the jet.

*Propeller tests, Sperry messenger airplane.*—In order to provide for true corrections for the effect of the Sperry messenger propeller in flight tests on the airplane, tests were made in the propeller research equipment on the aerodynamic characteristics of the propeller near zero thrust. The tests were run at several air speeds between 50 and 100 miles per hour, corresponding to the actual velocities of the airplane in flight. The results of these tests are being used in a report now under preparation.

*Drag tests, Sperry messenger airplane.*—Full-scale tests on the drag of a Sperry messenger airplane with the wings removed have been completed for comparison with the drag of a model tested at the same Reynolds Numbers in the variable-density tunnel.

The full-scale drag of the Sperry messenger fuselage, tail surfaces, and landing gear has been measured, and also the drag due to the windshield, cockpit, and the radial air-cooled engine.

*Air flow through the propeller plane.*—In order to study the effect of the fuselage on the air flow through the propeller, a survey is being made in the plane of the Sperry messenger propeller with the propeller removed. The flow is being surveyed both with the engine in place and with the engine removed and the nose faired. The information from such tests will be of value to propeller designers in that it will allow them to take into account the effect of the fuselage upon the air flow through the propeller. At the present time this effect is not definitely known and is a source of error in the design of propellers.

*FLIGHT RESEARCH.—Airships.*—During the last year the extensive data on the loads and stresses experienced by the U. S. S. *Los Angeles* in maneuvering flight and in flight in gusty air have been worked up to completion, tabulated, and submitted in report form to the Navy Department. The data thus available cover the pressures experienced at 300 points on the hull and tail surfaces in addition to the air speeds, angular velocities, angles of yaw, and control positions at the time these pressures were encountered. As was indicated by the preliminary results mentioned in last year's report, the final results show quite conclusively that the loads in flight in rough air greatly exceed those resulting from maneuvering the airship. Since a knowledge of the character of gusts likely to be encountered in rough air is essential for the proper design of airships, the preliminary study of the instantaneous changes in wind velocity and direction, mentioned in last year's report, is being continued.

In conjunction with the Bureau of Aeronautics, Navy Department, an additional series of speed and deceleration tests has been conducted on the U. S. S. *Los Angeles*. These tests were made both with and without the water-recovery apparatus in place, for the purpose of determining its effect on the speed, drag, and shape coefficient of the airship.

*Airplanes.*—The load distribution on high-speed airplanes is a subject of particular importance at the present time, because the high speed and great maneuverability of present-day pursuit airplanes have made it advisable to revise the methods of load computations and the loading specifications now in use. In this connection, the major portion of the flight-research

work this year has been on the problems of determining the air loads experienced on airplanes in all conditions of flight. Pressure distribution and acceleration tests have been made on a modern pursuit airplane in which the pressures were measured over the complete supporting surfaces, i. e., wings and tail surfaces, and the accelerations measured at the wing tip, fuselage tail, and the center of gravity of the airplane in all types of maneuvers, in some of which the loadings approached the design load factor. The investigation has been completed for the pressures experienced on the wings, vertical tail surfaces, and one-half of the horizontal tail surfaces. The pressures in the slip-stream portion of the wings and the remaining horizontal surfaces are to be measured, after which the pressure distribution on the fuselage will be investigated. A somewhat similar research has been completed on the air loads on the tail surfaces of a pursuit airplane where the pressures on a balanced-type rudder were of special interest. These tests were made in very violent maneuvers, a load factor of  $11\frac{1}{4}$  being attained in flight. Following the usual practice in this type of research, the pressures and accelerations were measured simultaneously and continuously throughout each maneuver, so that a time history of the pressures and accelerations is obtainable. The information obtained from previous tests on a wing and tail rib of two airplanes, a VE-7 and a TS, has been further analyzed and is being reported on in greater detail in a series of papers, each of which gives a time history of the pressures, air speed, and acceleration for a complete maneuver.

To investigate dangerous conditions in spinning flight the "dropping" tests instituted last year have been continued. In these tests flying models constructed to scale, both geometrically and with respect to loading and mass distribution, are dropped in a spin from a considerable altitude, and the rate of rotation and descent and the flight path are recorded by means of ultrarapid motion pictures. As yet only the effects of mass distribution have been investigated, but these show that the type of spin, flat or normal, can be controlled by the mass distribution, and indicate that dangerous spinning characteristics of an airplane may be avoided by proper apportioning of the weights. Tests on similar models are to be extended to include the effects of stagger, gap, and sweep back, and apparatus is being constructed to operate the controls after launching, in order to study control effectiveness in dangerous spins. To supplement the information on mass distribution obtained from the dropping tests, the full-scale moments of inertia of a number of airplanes, particularly those that evidenced unusual spinning characteristics, have been measured. For further information, the wing and tail pressures and loadings are being determined during spins in the pressure-distribution tests on a pursuit airplane, mentioned above.

A research on the water-pressure distribution on the bottom of a seaplane hull at landing and while taxiing has been completed for a single-float seaplane. The water pressures were measured in landings, take-offs, and in taxiing under a variety of wind and water conditions sufficient to assure obtaining the maximum pressures likely to be encountered in service. The pressure apparatus is now being prepared for a similar research on a boat-type seaplane.

Recent wind-tunnel experiments have indicated the possibility of improving the aerodynamic characteristics of wings by removing the boundary layer (the inert layer of air that clings to a wing section) either by sucking it into the interior of the wing or by blowing it off with air discharged under pressure. To determine the practicability of improving an airplane's performance by this means a series of flight tests was conducted in which the boundary layer of the upper wing of a biplane was removed by the pressure method. The tests were of a preliminary nature only, in that a wing already available was adapted to the purpose and an N. A. C. A. supercharger was used to supply air under pressure to the slots in the top of the wing. The tests indicated that the pressure method of boundary layer removal gave little promise of success, particularly on the type of wing section used. Further flight tests on boundary layer removal by suction methods are contemplated but will await more complete wind-tunnel data.

The subject of increased range of vision of the pilot in airplanes for combat purposes has received considerable attention lately from the services, and to demonstrate the effect of a cut-out center section on performance a series of tests was conducted on a training type biplane

with various types of cut-out center sections with and without wing tip shields at the cut-out portion of the wing. The tests show that a very considerable increase in forward and upward vision can be realized at a sacrifice of approximately 12 per cent in speed and climb. The cut-outs with shielding showed little improvement over a cut-out having elliptical tips at the open portion.

The lift and drag characteristics of the Sperry Messenger airplane equipped with R. A. F. 15, U. S. A. 5, U. S. A. 27, and Göttingen 387 wings, determined in flight tests last year, have been recomputed, using the information on propeller characteristics recently obtained in the propeller research equipment. The same propeller and airplane were used in the propeller tests as were used in flight. The corrections necessary are very slight and the results which have been held awaiting this confirmation are ready for publication.

Flight tests on five propellers on a VE-7 airplane have been completed and a report prepared.

*Miscellaneous.*—Preparations are being completed for a research on the comparative maneuverability of a number of modern airplanes of the pursuit and observation types, in which special attention is to be directed toward the determination of the flight path. Considerable study has been given to various methods of measuring an airplane's flight path in maneuvers, and one method showing considerable promise of success has been developed. By it, from measurements made in the airplane, the flight path may be determined to a greater degree of accuracy than has heretofore been possible. Another method incorporating motion pictures and triangulation from the ground has been partially developed.

Some time and study has been spent in assisting officials of the Guggenheim safe aircraft competition in formulating requirements of a safe airplane and prescribing methods of conducting the required flight tests.

**INSTRUMENT RESEARCH AND DEVELOPMENT.**—The attainment of high speed, greater maneuverability, and the resultant high acceleration of the modern military airplane used in connection with the various flight researches at the Langley Memorial Aeronautical Laboratory have called for greater refinements of the optical recording instruments which have been developed for the various flight researches. To meet these requirements a number of the former instruments have been remodeled and improved and several new instruments have been constructed. Among the remodeled and newly developed instruments are the following: A new recording turn meter, an airplane performance recorder, a new automatic observer, and a recording fuel flow meter.

In the study of the load on the PW-9 airplane during maneuvers it was found that turn meters used in previous tests where the angular accelerations were relatively low were subject to considerable error in cases of high angular accelerations. It was necessary, therefore, to make a complete analysis of the conditions under which the instrument would be required to operate and to so design one that the errors would be minimized. During this study the turn-meter calibrating table which was placed in operation last year was found to be invaluable in making the proper adjustments of sensitivity, natural period, and damping, and for the duplication of instruments with identical constants. It has also been found necessary to use the turntable for the adjustment of the three-component accelerometers to duplicate exactly sensitivity, natural frequency, and damping. This additional requirement has been found necessary for investigations on seaplanes to determine the loading on the landing structure during the take-off and landing periods. Along with the study of damping problems a new type of dashpot has been designed to prevent spilling and the evaporation of the damping fluid.

The increasing number of airplane performance tests conducted at this laboratory has made it necessary to incorporate the recording elements of three instruments into one. This new instrument, known as a performance recorder, consists of a standard N. A. C. A. instrument case in which are mounted a barometer, an air-speed meter, and a galvanometer. The galvanometer forms part of a resistance-type thermometer and records free-air temperature. Considerable study of the design of the strut element or bulb to minimize lag and at the same time to produce a rugged instrument has resulted in a recorder which operates very satisfactorily

and requires a minimum of service. The combination instrument makes a continuous record of barometric pressure, air speed, and air temperature, from which the airplane performance can readily be calculated.

Increased use of the automatic observer for flight tests and for laboratory tests has necessitated its redesign to eliminate service difficulties, increase the number of instruments which can be photographed, increase the frequency at which the pictures are taken, and reduce the space requirements. The new automatic observer meets these requirements and photographs the indications of as many as 12 standard instruments at the rate of 12 exposures per minute. The instrument has been found of value in laboratory tests where simultaneous readings are required from a number of indicating instruments, and through its use it is possible to complete a given series of tests in a much shorter time, with fewer personnel, and with an accurate definite record of the readings, unaffected by the personal element.

For some time there has been a definite need for an accurate fuel flow meter for use in flight researches on power plants, and the investigation of several types of instruments was reported last year. As a result of these investigations, an instrument has been built and given considerable service, and shows promise of fulfilling this need. It consists of a Venturi nozzle and two differential pressure bellows interconnected with a mechanism for operating a Wheatstone bridge in such a manner that the galvanometer registers rate of fuel flow. The instrument is not affected by the vibration of the airplane, and its installation may be made anywhere in the fuel line.

It was reported last year that an investigation was in progress to determine the practicability of the use of carbon disks in conjunction with the cathode ray oscillograph as an engine indicator for high-speed aircraft engines. Continuation of this investigation has shown that such an apparatus would be unduly complicated and would require much careful research before such equipment could be designed for practical use. Therefore it was decided to investigate the possibilities of a simple diaphragm type optical engine indicator, and very promising results have been obtained. One instrument has already been constructed which records upon a photographic film the pressure in the combustion chamber of a fuel injection engine during its operation. While the instrument is still in the experimental stage the results indicate that a very satisfactory indicator can be built upon this principle. It consists of an optical system attached to a small steel diaphragm, which is inserted directly through the spark plug hole of the engine cylinder head flush with the wall of the combustion chamber. The minute deflections of the diaphragm are optically amplified and recorded upon a moving film, thus resulting in a diagram of the pressures within the engine cylinder against time.

The new propeller research equipment recently put into operation was found to require some form of device for automatically controlling the air speed within close limits throughout the working range. To meet this need an instrument was constructed which is primarily a sensitive balance operated by small changes in pressure, electrical circuits being operated to maintain a constant air speed at any predetermined value by controlling the propeller speed. The instrument has been installed and used in connection with the 6-inch wind tunnel where experience has shown that it may be expected to operate very satisfactorily in controlling the air speed of the larger tunnel.

There have been numerous other investigations and instrument developments during the past year, such as a propeller protractor, a number of stop-watch control mechanisms, an automatic angle-of-attack mechanism for use in pressure-distribution investigations, and investigations of various oils suitable for instrument damping, which investigations are still in progress.

#### WASHINGTON NAVY YARD

*Airplane models.*—The 8-foot wind tunnel of the Washington Navy Yard has been used almost entirely for airplane model tests. During the past year 34 complete tests in pitch and yaw were made on 22 models representing 17 designs. Seventeen of the tests were of a research nature and an equal number were made on either design studies or existing service airplanes.

Following the usual practice, two models were tested in both landplane and seaplane arrangement, two models were tested with two wing sections, one model was tested with two tail surfaces, and two models were tested with three tail surfaces. These tests have supplied valuable data for the design requirements of the Bureau of Aeronautics. In this connection, it is to be noted that flight tests appear to confirm fully the wind-tunnel indications of high efficiency for the Göttingen 398 wing section and its modifications, excellent agreement having been obtained.

Two of the tests on tail surfaces are of general interest. The original PN-7 was found to have neutral static longitudinal stability for angles of attack between  $5^\circ$  and  $12^\circ$ , and this was verified by flight tests. Wind-tunnel tests with a new horizontal tail surface having the same area as the original but with an aspect ratio of 4.4 instead of 2.2 showed very satisfactory static stability which was also verified by flight tests. The original T3M-1 horizontal tail surfaces had a very thick section, and the control and stability were only fair according to both wind-tunnel and flight tests. A wind-tunnel test on this model fitted with tail surfaces of a comparatively thin section showed a considerable improvement in both control and stability. Flight tests have not yet been made to verify this, however.

*Airfoils and wings.*—Owing to an unusually large amount of urgent work it has not been practicable to carry out the airfoil testing program laid out several years ago. This work will be carried over until it can be done without holding up more important tests.

*Control surfaces.*—Two or more rudders or elevators are frequently tested on an airplane model as a part of the design research program, but occasional tests are made on control surfaces alone. During the past year three such models were tested for lift, drag, and hinge moments.

*Lighter-than-air craft.*—Drag tests have been made on a streamline form having for its longitudinal cross section one loop of the curve  $r = K \cos (4.8\theta)$ . The drag per unit area of the maximum cross section was very low, but the prismatic coefficient of the model was also low and the drag per unit volume not so favorable.

For more than two months the entire facilities of the wind tunnel were employed in research work on three rigid airship models fitted with various control surfaces. Drag readings were taken at  $0^\circ$  pitch and yaw and at a series of wind speeds with the models in various conditions ranging from the bare hull to complete appendages. Tests were made in pitch and yaw on one of the models fitted with various combinations of appendages and control surfaces. Damping coefficients were also measured.

*Miscellaneous tests.*—Tests have been made in the 4-foot wind tunnel on three float models and two fuselage models in addition to the series previously described. It has developed during these tests that the drag coefficient is quite sensitive to comparatively small changes in the lines and that further work is desirable. A variation of approximately 100 per cent in drag was found between two models of the same general appearance.

The pressure drop or resistance of wire screens of varying wire and mesh sizes is now being systematically investigated in the 4-foot wind tunnel.

#### BUREAU OF STANDARDS

*Wind-tunnel investigations.*—During the year the installation of apparatus at the Bureau of Standards for measurements of aerodynamic characteristics of airfoils at high speeds was completed. The equipment provides a continuous air stream 2 inches in diameter of speeds ranging from 0.5 to 1.08 times the speed of sound (375 to 825 miles per hour, approximately). The characteristics of 24 airfoil sections have been determined at speeds of 0.5, 0.65, 0.8, 0.95, and 1.08 times the speed of sound at angles of attack from the angle of zero lift to  $+24^\circ$ . The airfoils were of 1-inch chord, extending entirely across the air stream and represented members of the R. A. F. and Clark Y families commonly used in propeller design. The measurements form a part of a general program outlined by the conference on propeller research organized by the National Advisory Committee for Aeronautics and will be published as a technical report of the committee. The results show the Clark Y sections to have the greater efficiency at high speeds and indicate the desirability of moving the maximum ordinate back on airfoils intended for speeds equal to the speed of sound.

The investigation of turbulence in wind tunnels has been continued in cooperation with the National Advisory Committee for Aeronautics. The possibilities of the use of a hot wire have been extensively investigated and encouraging results have been obtained.

The subject of wind pressure on engineering structures has received further attention. The distribution of pressure over a model of a factory building has been measured and the results are being prepared for publication. The model experiments on chimneys are being supplemented by observations of the pressure distribution around an experimental chimney 10 feet in diameter and 30 feet high constructed on the roof of one of the buildings of the Bureau of Standards. Preliminary observations indicate that the model experiments carried out above the critical region give fairly reliable indications of the force on a full-scale chimney.

*Aeronautic instrument investigations.*—Progress has been made on the design of temperature elements having a small time lag for use in the electric-resistance type of air thermometers. These instruments were constructed for the National Advisory Committee for Aeronautics for use in performance tests of aircraft. Resistance elements have been constructed which have a thermometric time lag of 4 seconds when exposed in an air stream of 17 miles per hour, compared with a lag of 17 seconds at the same air speed for the elements previously built. This corresponds to a time lag of about 2 seconds at flying speeds, which reduces the lag error in the measurement of the air temperature during the climb of fast airplanes from about 0.9° C. to 0.2° C. A report entitled "Lag of thermometers and thermographs for aircraft," has been published in the Monthly Weather Review.

The development and construction of an altimeter corrected for air temperature has been completed during the year for the Bureau of Aeronautics of the Navy Department. The temperature correction feature relates to the application of a correction for the purpose of taking account of the temperature term in the altitude formula. The ground-level air temperature is set up in the instrument on a small drum showing through the dial. Altitudes are then indicated which take account of an average variation of temperature with altitude for the set value of ground-level temperature. The instrument also contains the usual devices which compensate for the effect on the reading due to the variation in temperature of the instrument. The altitude range is 15,000 feet.

Research relating to the properties of elastic materials used in instruments has been continued for the National Advisory Committee for Aeronautics. Three of the Ogilvie air-speed indicators containing special rubber diaphragms were returned for tests in May, 1927, from the Langley Memorial Aeronautical Laboratory. No appreciable change in the stiffness of the diaphragms was evident, covering a period of 1½ years of use and three years since manufacture. Further progress has been made on the research relating to elastic hysteresis. The damping of a tuning fork of Armco iron was determined experimentally and a relation developed between the statical hysteresis modulus and the damping. Measurements on an Armco iron bar, loaded at one end and fixed at the other, have shown that the statical hysteresis is the same for cycles of equal load range, but different terminal loads. Reports are in preparation on this work. A large amount of experimental data has been accumulated on the change in the modulus of torsion of diaphragm and spring metals in the temperature range +40° C. to -20° C. A report on tension experiments on diaphragm metals was submitted to the National Advisory Committee for publication as a technical note.

An investigation is in progress for the National Advisory Committee for Aeronautics on suitable damping liquids for aircraft instruments. An ideal damping liquid of a required viscosity should be nonvolatile, nondrying, and chemically permanent and have a small temperature coefficient of viscosity in the temperature interval experienced by aircraft. Bearing in mind the above requirements the viscosity of a number of liquids and mixtures has been measured in the temperature range from +40° to -30° C.

Special emphasis was placed on the development and improvement of lighter-than-aircraft instruments and of flight-test instruments for the Bureau of Aeronautics. This has included the construction of an improved superheatmeter, the addition of an air-speed recorder to a barograph, the construction of a bimetallic element thermograph, and other refinements and improvements. Progress has also been made in the preparation for the Bureau of Aeronautics of the general report on capillary-type rate-of-climb indicators.

## MATÉRIEL DIVISION, ARMY AIR CORPS

*General.*—During the past year the operation of the wind tunnels at McCook Field has been seriously handicapped by the necessity of moving the equipment to the new Wright Field. The 5-foot wind tunnel has been used almost exclusively for the various routine service tests of model airplanes. In the high-speed 14-inch wind tunnel a study of air flow was made by visual means. The surface-flow photographs were made by a method used by the General Electric Co., which consists of painting the model with a mixture of lampblack and kerosene; the air flow then records its direction by scoring fine channels in the pigment, resulting in "surface lines," which may be readily photographed. A further study was made in the 14-inch wind tunnel of air flow around airfoils at various angles of attack and around different bodies. The investigation also included a study of the effect upon the air flow of removing the boundary layer.

No major change has been made in the apparatus of the wind tunnels, but the mechanisms of the wire balance in the 5-foot wind tunnel has been refined by replacing the pulley in the "dead line" with levers mounted on knife edges.

*Officers' school.*—The usual period required by the McCook Field officers' school was devoted to the instruction of a class of 11 officers in the practice and technique of wind tunnel operation.

*Service tests.*—The majority of the airplane models were tested both on the N. P. L. balance at 40 miles per hour and on the wire balance at 100 miles per hour. This procedure was followed for tests on several models in order to study the effect of speed upon the burbling of the wing and to compare the two balances. The airplane model tests include the following:

Scale of model	Name of model	Method
	Light bombardment types:	
One-fortieth.....	Atlantic XLB-2.....	N. P. L. balance at 40 m. p. h.
One thirty-sixth.....	Keystone XLB-3.....	Do.
One forty-eighth.....	Glenn Martin XLB-4.....	Wire balance at 100 m. p. h. and N. P. L. balance at 40 m. p. h.
One thirty-sixth.....	Keystone XLB-5.....	N. P. L. balance at 40 m. p. h.
One-sixtieth.....	Woolsey bomber.....	Wire balance at 100 m. p. h.
	Heavy bombardment types:	
One-fiftieth.....	Keystone XB-1.....	Wire balance at 100 m. p. h. and N. P. L. balance at 40 m. p. h.
One-fortieth.....	Curtiss XB-2.....	N. P. L. balance at 40 m. p. h.
One forty-eighth.....	Atlantic XHB-2.....	Do.
One forty-fourth.....	Matériel division H. B.....	Wire balance at 100 m. p. h.
One-fortieth.....	Transport type: Fokker V-VII.....	Wire balance at 100 m. p. h. and N. P. L. balance at 40 m. p. h.
	Observation types:	
One-twelfth.....	Matériel division N. O.....	Wire balance at 100 m. p. h.
One twenty-fourth.....	Douglas XNO-2.....	Do.
One twenty-fourth.....	Thomas-Morse XO-6.....	N. P. L. balance at 40 m. p. h. and wire balance at 100 m. p. h.
One-twelfth.....	Ground attack type: Matériel division G. A.....	Wire balance at 100 m. p. h.
One-eighteenth.....	Pursuit type: Curtiss P-1.....	N. P. L. balance at 40 m. p. h.

Two 6 by 36 inch airfoils (Clark Y and R. A. F. 15) with trailing edge flaps were tested. These airfoils were tested at 100 miles per hour on the wire balance. The N. A. C. A. 81-J airfoil was tested on the wire balance at 100 miles per hour. Several of the propeller series of airfoils which were tested in 1926 were retested to check the previous work.

*Miscellaneous tests.*—Tests were made upon  $\frac{1}{4}$ -scale models of the Douglas O-2C and Curtiss O-1 airplanes and cellules at all angles of attack ( $0^\circ$  to  $360^\circ$ ). This work was done in connection with the study of the spinning characteristics of these airplanes.

An autogyro model of the la Cierva type was tested for lift and drag.

✓ Preliminary "flutter" test on specially constructed airfoil was made.

Other miscellaneous tests included the tests of wind-driven generators and earth inductor compasses, tests on airplane fabric, a test of a commercial windmill, and a test of a model airplane wheel and tire.

## EDUCATIONAL INSTITUTIONS

At a conference of representatives of educational institutions in this country engaged in the teaching of aeronautical engineering, held in Washington on December 10 and 11, 1926, under the auspices of the Daniel Guggenheim Fund for the Promotion of Aeronautics, at which conference the National Advisory Committee for Aeronautics, as well as the matériel division of the Army Air Corps, was represented, the programs of aerodynamic research to be carried on by the various educational institutions were discussed. As agreed upon at this conference, these research programs have since been submitted to the Daniel Guggenheim Fund.

Through the courtesy of the Guggenheim Fund, copies of these programs have been transmitted to the National Advisory Committee for Aeronautics. The principal items of aerodynamic investigation included in the research programs received from the educational institutions of the United States are as follows:

*Massachusetts Institute of Technology:*

1. Continuation of investigations of mutual interference effects of airplane propellers and other parts of the airplane. This is to include the effects of radical changes in fuselage form and location, effect of radical engine cylinders with different types of cowlings, the effect of different propellers on performance, the effect of nacelles in multiengine airplanes, and the measurement of elevator and rudder hinge moments.
2. Measurements of flow around a model airplane as influenced by the propeller, particularly in the region near the tail.
3. Possible experimental determination of actual air flow near the blades of the propeller as opposed to the mean air flow.
4. Pressure distribution on the tail with slip stream.

*New York University:*

1. Corrections for calculations of performance test, with special reference to the Daniel Guggenheim Safe Aircraft Competition.
2. Wind-tunnel tests for comparative efficiency of an engine nacelle placed at different positions between the wings of a biplane.
3. Empirical design formulæ for downwash behind monoplane and biplane wings.

*Stanford University:*

1. An experimental investigation of the performance characteristics of a series of five metal model propellers in a free wind stream and in combination with a model of a VE-7 airplane.
2. An experimental investigation of air propellers in yaw. It is planned to conduct this investigation on a series of United States Navy standard models at angles of yaw from  $0^\circ$  to  $20^\circ$ .
3. An experimental investigation of the rotational velocity of the slip stream of air propellers. It is planned first to determine the rotation in the slip stream of a series of United States Navy standard model propellers and then to investigate the effect of straightening vanes upon the power absorbed and efficiency.
4. An experimental and theoretical investigation of the causes of discontinuous air flow. It is desired to formulate criteria which will enable the prediction of the departure of smooth flow from the surface of an airfoil or streamline body.
5. An experimental investigation of the induced drag of airfoils of high aspect ratio. It is intended to test airfoils having aspect ratios from 6 to 15 and to compare the results with the predictions of the Lanchester-Prandtl theory.

*California Institute of Technology:*

1. Theoretical investigations in boundary layer, heat conduction, and other aerodynamical subjects.
2. Full-scale construction and free flight-testing of a new model of the Merrill type stagger decalage biplane.
3. Installation and calibration of apparatus in the Daniel Guggenheim Laboratory of the institute.

## REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

## ORGANIZATION

The committee on power plants for aircraft is at present composed of the following members:

Dr. S. W. Stratton, Massachusetts Institute of Technology, chairman.  
George W. Lewis, National Advisory Committee for Aeronautics, vice chairman.  
Henry M. Crane, Society of Automotive Engineers.  
Prof. Harvey N. Davis, Harvard University.  
Dr. H. C. Dickinson, Bureau of Standards.  
William F. Joachim, National Advisory Committee for Aeronautics.  
Lieut. Commander James M. Shoemaker, United States Navy.  
Prof. C. Fayette Taylor, Massachusetts Institute of Technology.  
Capt. T. E. Tillinghast, United States Army, matériel division, Air Corps, Wright Field.

## FUNCTIONS

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power-plant research are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding aeronautic power-plant research in progress or proposed.
4. To direct and conduct research on aeronautic power-plant problems in such laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Bureau of Standards, and the industry upon this subcommittee, it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research.

The committee on power plants for aircraft has direct control of the power-plant research conducted at Langley Field and also of special investigations authorized by the committee and conducted at the Bureau of Standards. Other power-plant investigations undertaken by the Army Air Corps or the Bureau of Aeronautics are reported upon at the meetings of the committee on power plants for aircraft.

## LANGLEY MEMORIAL AERONAUTICAL LABORATORY

**ENGINE RESEARCH.—*Fuel injection engine.***—The increased thermal efficiency and low fuel consumption theoretically obtainable with the high-speed oil engine as compared with the carburetor engine, make the use of the oil engine particularly attractive for both military and commercial aircraft. The use of an oil engine for this type of service requires, however, maximum engine reliability with high power output per pound of engine weight, and low fuel consumption.

As previously reported, the two factors of major importance in the design of an aircraft oil engine are, first, the complete preparation of the fuel charge to give practically instantaneous autoignition on injection into the combustion chamber and second, the efficient distribution of the fuel throughout the combustion chamber by use of proper oil sprays and the necessary degree and type of combustion chamber turbulence, which will give combustion of the fuel early in the power stroke. The amount of research work done in this country and abroad toward obtaining the solution of these problems has greatly increased within the last year. The committee's work has included the investigation of the effects of turbulence as produced by combustion chamber design, the analysis and testing of various types of fuel valves and injection

pumps by means of special spray photography apparatus and by engine tests, and the analysis of theoretical problems in connection with the calculation of oil engine cycle efficiencies.

*Engine performance—Combustion chamber design.*—The investigation of the effect on engine performance of the various degrees of turbulence brought about by combustion chamber design has been continued with a single-cylinder Liberty engine and the second bulb-type cylinder head. As previously reported, the engine performance of this type of cylinder head has been determined with a nine-sixteenth-inch orifice having sharp edges, rounded edges, and with the cylinder side of the orifice flared to discharge the burning gases over one-half the piston area. The orifice has now been flared on the bulb side to distribute the air more thoroughly in the bulb. All tests have been made at a compression ratio of 13.5. The corresponding compression pressure at 1,600 revolutions per minute is 440 pounds per square inch. The fuel injection system used includes a cam-operated impact-type fuel injection pump and a spring-loaded fuel injection valve designed to give a high degree of fuel atomization. The engine performance was determined for speeds from 600 to 1,800 revolutions per minute, with the orifice flared to distribute the gases from the bulb over one-half the piston area, and a constant fuel quantity equal to 83 per cent of the full-load fuel quantity. The indicated mean effective pressure throughout the entire range of speeds was approximately 110 pounds per square inch and the fuel consumption 0.39 pound per indicated horsepower per hour. The maximum cylinder pressure varied from 690 pounds per square inch at 600 revolutions per minute to 750 pounds per square inch at 1,800 revolutions per minute. Flaring the bulb side of the cylinder orifice resulted in increasing the indicated mean effective pressure at full load and 1,600 revolutions per minute from 109 pounds per square inch to 113 pounds per square inch. The corresponding fuel consumptions on an indicated basis were 0.48 and 0.46 pound per indicated horsepower per hour. This represents a gain in mean effective pressure of 3.6 per cent and a reduction in the fuel consumption of about 4 per cent. The maximum cylinder pressure at full load, as indicated by a diaphragm type maximum cylinder-pressure indicator, was 750 pounds per square inch for both series of tests. Along with this investigation on the effects of turbulence, many tests have been made with this engine to determine the effects of progressive piston alterations on the performance of special types of gas and oil piston rings.

Two additional cylinder heads have been designed and constructed under this investigation for the Universal test engine. The first cylinder head has a vertical disk-shaped combustion chamber located between the inlet and exhaust valve, with means for varying the amount and direction of the turbulence. This change in air turbulence is obtained by variations in large removable orifices connecting the cylinder with the disk-type combustion chamber. A wide range of cylinder-orifice areas and shapes has been selected to permit the determination of the engine performance for a complete range of air-fuel ratios. The fuel injection pump is cam-operated and equipped with means for timing the injection and determining the rate of fuel pressure rise and the point of injection cut-off. The fuel valve used is of the automatic, spring-loaded, stem type and can be fitted with nozzles having one or more orifices. An investigation on nozzles using various arrangements and sizes of small round orifices will be made sufficiently complete to make a comparison between engine performance with the multiple round orifices and with slotted and annular orifices. The minimum diameter of the orifices investigated will be 0.004 inch. This cylinder head will be tested at compression ratios from 11.7 to 13.6, speeds from 800 to 2,400 revolutions per minute, and a controlled maximum cylinder pressure of about 800 pounds per square inch. Preliminary tests of this cylinder head have included the determination of the volumetric efficiency for speeds from 1,200 to 2,000 revolutions per minute with four cylinder orifices having areas of 1.95, 2.60, 3.25, and 3.90 square inches.

The preliminary power tests made with this cylinder head and nozzles having from three to five orifices show that the performance to date is poorer than that previously reported for fuel injection valves having annular orifices. The decrease in engine performance obtained when using small round orifices in the injection valve nozzle indicates that the sprays are not sufficiently well atomized nor distributed for high-speed oil engines. This was expected from theoretical considerations, and was further indicated by spray distribution analyses made in

connection with certain fuel-spray photography investigations. The combinations of orifices which have been used to date with a single fuel injection valve have prevented the attainment of the variable fuel injection rates for which the injection-pump cam was designed.

The second cylinder head has a horizontal, disk-shaped combustion chamber designed to conform to fuel spray shapes and provided with openings for the use of one or more injection valves. Varying degrees of turbulence within the combustion chamber may be obtained with this cylinder head by varying the shape, height, and diameter of a short, large-diameter displacer on the piston. The performance of this cylinder head will be determined for various degrees of fuel preheating by using exhaust and electrical fuel preheating injection valves. The castings for this cylinder head are being machined.

One of the fundamental factors which control the performance of a high-speed oil engine is the rate at which the fuel and air are mixed and burned. If the combustion proceeds too rapidly or with shock, it results in excessive cylinder pressures. Too slow a combustion rate, giving low maximum cylinder pressures because of late ignition and after burning, results in poor engine performance. Consideration of these factors has led to the design of a cylinder unit which will control combustion in a high-speed oil engine by mechanical displacement of the vaporized and ignited oil charge and the air for its complete combustion from small cam-operated auxiliary cylinders into the power cylinder. This cylinder design will permit a considerable increase to be obtained in volumetric efficiency, and will have several desirable characteristics in connection with the construction of radial air-cooled engines because of its shorter cylinder length. The fuel-injection pump for this cylinder-head unit is cam-operated and the start and stop of injection are controlled by a poppet type by-pass valve. The pump-control levers will simulate the throttle and spark controls of a carburetor aircraft engine.

*Engine performance—Engine variables.*—Investigations conducted with standard Liberty-type aluminum-alloy pistons have indicated the necessity for a reduction in the friction of the rings and the pistons, and an increase in strength of the piston crown and bosses for oil engine operation. A skeleton-type piston has been designed for high-speed oil engine service to give maximum power transmission with minimum mechanical and thermal distortion. The pistons are constructed of "Y" alloy and weight nine-tenths as much as the standard Army Liberty type of aluminum-alloy piston. The loading on the piston crown is transmitted by a strut of large section directly to the mid-section of the piston-pin bosses. The skirt of the piston is insulated from the crown and ring belt by a slot. The thrust faces of the piston have been designed to operate at a loading of 250 pounds per square inch at a cylinder pressure of 1,000 pounds per square inch and an engine speed of 2,400 revolutions per minute. The thrust faces will be lubricated by oil under pressure from the wrist pin. These pistons will be tested in single-cylinder test engines with various piston-ring designs and assemblies for the determination of the major factors affecting power transmission and friction losses.

The investigation of factors influencing the mechanical efficiency of the oil engine has shown the need for reducing the friction mean effective pressure by reducing the wall pressure of piston rings. Special piston rings have been designed to permit flooding of the cylinder walls with oil under pressure. The inertia and friction of the ring against the cylinder wall, and the inertia, impact, and hydraulic pressure of the oil are used to seal the land and cylinder-wall surfaces against leakage. The normal wall pressure of the piston rings is practically zero. Progressive alterations to the piston have reduced the oil consumption of the engine with one autoseal oil ring to about one-third the initial oil consumption, and to about two-thirds the consumption obtained with three standard Liberty piston rings.

Indicators for engines which use diaphragms or disk valves to measure engine-cylinder pressures have inherent errors, because of the inertia of their moving parts and the difference in the area exposed to the cylinder gases and to the balancing gas pressures. Engine tests have been undertaken to determine the effect of varying the shape, mass, and displacement of the moving element in a diaphragm-type maximum-cylinder-pressure indicator.

*Fuel-injection pumps and valves.*—The relative amounts of fuel and the rates of fuel injection required to give the constant volume and constant pressure burning for theoretical dual-com-

bustion-cycle indicator cards have been calculated during the past year. These theoretical calculations have been used in the design of a cam for a fuel injection pump to deliver fuel at the rates required to control combustion so as to obtain the cylinder pressures as given by the theoretical indicator card. Injection, distribution, ignition, and combustion lags, as determined from bench tests and theoretical calculations, have been taken into account in the design of this cam to control the proportion of constant volume and constant pressure combustion. The injection valve used with this fuel injection pump is of the automatic, spring-loaded stem type, with a narrow conical seat at the end of the stem. Preliminary tests have been made with injection nozzles having combinations of from three to five round orifices in the cylinder head having a vertical disk-type combustion chamber. Test work now in progress will cover the range of efficient operation of multi orifice injection nozzles using small round orifices.

Tests made with the second N. A. C. A. bulb-type cylinder head indicated that there was only a slight increase in performance to be obtained by extending the fuel injection valve nozzle short distances into the bulb. The maximum length of extension previously tested was one-half inch. Since the  $\frac{9}{16}$ -inch orifice has been flared on the bulb side, the fuel nozzle has been extended  $1\frac{1}{2}$  inches into the bulb. This extension has been provided with a series of copper fins designed to increase the rate of vaporization of the fuel within the bulb. The orifice in the fuel-valve extension is designed to inject the fuel directly into the nine-sixteenths cylinder-to-bulb orifice which should give considerably improved mixing of the fuel and air. It is expected that the large surface area of the fins will reduce the time lag of autoignition of the fuel by acting as a hot surface within the precombustion chamber.

For successful high-speed oil engine operation, the time lag of autoignition must be reduced to a minimum. Two fuel injection valves have therefore been designed to study the effect of the thermal preparation of the fuel before injection on the lag of autoignition and engine performance. In the first valve design the heat required to prepare the fuel is taken from the exhaust gases by a series of fins. The second valve is provided with electric heating coils for heating the fuel. Fine wire thermocouples will be used to determine the progressive temperature rise of the fuel as it passes through the fuel injection valve. A direct comparison of the electric and exhaust heated valves will be made on the same cylinder heads.

**FUEL-INJECTION RESEARCH.**—The spray photography apparatus constructed and developed by the staff of the committee has permitted the extended photographic study of the characteristics of injection systems and the fuel sprays produced by them. Records of the start, development, cut-off, and distribution of the fuel sprays are obtained by photographing them at rates of from 2,000 to 4,000 per second with an exposure of less than one-millionth second. Injection pressures up to 12,000 pounds per square inch and spray chamber pressures up to 600 pounds per square inch are used. The spray-photography apparatus has been described in previous reports of the committee.

The time lags of an injection system are important in the design of high-speed oil engines. Additions to the spray-photography apparatus have made it possible to determine the time lags for the injection system used with the apparatus. In this system, oil under pressure is released by a cam and lever-operated timing valve to the injection valve tube to produce a spray from the injection valve. A record of the motion of the injection valve stem is obtained on a photographic film by means of an optical indicator. By coordinating this record with that of the series of spray photographs, the time lags for various test conditions for the pressure waves to travel the valve tube length can be obtained.

A research on the velocity of pressure waves and the time lags in an injection system between the instant the timing valve is lifted and the appearance of the spray from the injection valve has been completed. The factors investigated included the injection valve tube length and diameter, initial fuel pressure in the tube, injection pressure, and injection valve opening pressure. The effects of these factors on the lag of operation of the timing and injection valves and on the velocity of pressure waves in the systems have been investigated. It was found that the timing valve lag could be largely accounted for by the time required to release the timing valve stem from compression by the spring. The injection valve opening pressure had

the greatest effect on the injection valve lag, an increase in the opening pressure from 2,000 to 6,000 pounds per square inch causing the time lag of 0.0003 second for a 46-inch valve tube to increase 300 per cent. The velocity of the pressure waves was approximately that of a sound wave, but varied slightly with the initial tube pressure and the injection pressure. The injection valve tube length had the greatest effect on the wave velocity. Other results which can not be readily summarized here have been obtained.

Analyses of the experimental data obtained during the previous year have been completed. Reports have been prepared on the factors affecting the exact reproducibility of penetration and the cut-off of oil sprays, and on the factors in the design of centrifugal type injection valves for oil engines.

Analyses of experimental data have been completed for the investigation of the effects of fuel spray and spray-chamber gas densities and viscosities on the characteristics of fuel sprays. A logarithmic relation was found to exist between the chamber gas density and the spray volume at time intervals of from 0.002 to 0.004 second after the appearance of the sprays. An approximate application of the penetration data to the conditions of varying pressure and density in an engine during injection of the spray was made.

A complete description of the spray-photography apparatus in its present form has been published, together with representative spray photographs and curves. The effect on spray characteristics of injection pressure, chamber gas density, fuel-oil specific gravity, and of two factors in the design of a centrifugal type injection valve are given.

Both experimental investigations and mathematical analyses of the operation of the spray photography timing valve have been made. The effect of spring tension and of length of injection-valve tube on the time-lift diagram of the valve stem have been investigated and compared with the cam contour. The rates of fuel-pressure rise at the timing valve and in the injection valve tube have been computed and found to compare satisfactorily with the actual test results. The timing valve has been used as a positively operated injection valve, and records have been taken of the opening and closing of the valve.

A research has been undertaken to determine the effects of the weight of the moving parts, amount of movement, amount and type of operating forces, and the type of injection nozzle, on the lag of injection of the valve and on the characteristics of the fuel sprays. Injection valves already available will be used, and new valves designed to permit a comprehensive investigation of the above variables.

The design of various devices to be added to the present spray-photography apparatus has been undertaken in order to permit the study of the characteristics of combustion of atomized fuels for oil engines. No reliable data could be found from which the amount of heat which will be lost to the water jackets of the spray combustion chamber during the air heating and combustion periods could be computed. These data have been determined experimentally with a water-cooled cylinder in which the air was heated electrically. Heat transfer coefficients for this apparatus have been determined for a range of air temperatures up to 700° F., and for air pressures up to 50 pounds per square inch. The laws controlling the heat transfer for the conditions of these tests have been used for computing the size and capacity of the heating apparatus for the new spray combustion chamber.

The work to date indicates that the new apparatus will consist of a water-cooled chamber with fused quartz windows, a separate heating chamber, and apparatus for producing turbulence during injection of the fuel sprays. It will be possible to simulate the actual conditions of temperature, pressure, combustion-chamber shape, and turbulence in an engine. Analyses and computations for the various apparatus for this work are reaching a point where actual design can be started.

**SUPERCHARGER DEVELOPMENT.**—*Supercharger analysis.*—An investigation is now being made to determine the fundamental and practical requirements to be met by aircraft engine superchargers in military and commercial service. The adaptability and performance characteristics of all types of compressors are being studied to determine to what degree each meets the requirements of an ideal supercharger. It is believed that this analysis will lead to the proper selection and further development of the best compressor for each service.

*Modifications to the Roots type supercharger.*—A mathematical and analytical investigation is being made to determine the possibility of improving the performance characteristics of Roots type superchargers by means of a suitable type discharge valve. This valve will materially reduce the inherent disadvantages of a Roots blower, namely, the pulsating air flow, the lower volumetric efficiency at the higher critical altitudes, and the return flow of air which requires its redelivery. The latter disadvantage results in an inefficient increase in the carburetor air temperature and in the power required. Both oscillating and rotating valves have been studied. These valves will be synchronized with the impellers so that they close after each charge of air is delivered and do not open until the next charge is compressed and ready to be delivered.

Some difficulty has been experienced in maintaining the most efficient and best mechanical impeller clearances on the Roots type supercharger because of the expansion of the impellers at the high temperatures that accompany the pressure ratios obtained at high critical altitudes. Increasing the clearances sufficiently to eliminate the possibility of scoring the impellers at these high temperatures results in a decrease in the volumetric efficiency which necessitates a corresponding increase in impeller speed to maintain the same air delivery. A set of steel impellers is being constructed to replace the present magnesium alloy impellers now used. The steel impellers will have a weight equal to or less than the magnesium impellers, and because of their lower coefficient of expansion will not expand as much as the aluminum case. This will permit the use of smaller clearances at assembly without danger of scoring the impellers or the case at the higher temperatures.

Some difficulty has also been experienced with impeller end clearances because of the axial shift of the impellers caused by initial looseness and slight wear of the balls and races in the impeller-locating bearings. Precision-type ball bearings with much less looseness between the races have been obtained to eliminate this axial shift. The wear will be reduced by filtering out the carbon and foreign matter from the lubricating oil.

These several changes will permit the use of smaller impeller clearances with safety, and will result in increased supercharger efficiency and in net engine performance and power.

*Effect of supercharger capacity on airplane performance.*—This research was undertaken to determine the effect of various amounts of supercharging on the performance characteristics of an airplane. The investigation will be carried out on a modified DH-4 airplane with a steel fuselage. This airplane is now being partially rebuilt for this research. To obtain different degrees of supercharging the speed of the same supercharger will be varied by driving it at 1.615, 1.957, 2.4, and 3 times engine speed. These supercharger speeds will give critical altitudes of approximately 12,000, 16,000, 21,000, and 28,000 feet, respectively. The changes in power with altitude of a supercharged and unsupercharged engine, the effect of supercharging on volumetric efficiency, and the fuel consumption of a supercharged engine in flight will be determined in this research.

*Problems incidental to supercharging.*—The determination of engine power in flight has been attempted by several methods. The results obtained differ considerably, depending on the method used. The use of calibrated propellers is probably the most satisfactory method that has yet been tried, but this method may introduce errors as high as 10 per cent. These errors may be caused by bending and twisting of the propeller, which vary with changes in altitude; warping, which is caused by weathering or aging, and errors in correcting the power of a calibrated engine for changes in temperature and pressure. A Bendemann hub dynamometer has been used for determining engine power in flight and in calibrating two propellers in flight. The results obtained with the hub dynamometer were more satisfactory than the results which have been obtained with any other method used. Work is now in progress to determine the most suitable type hub dynamometer as a means of accurately measuring power in flight. The requirements to be met by a hub dynamometer have been formulated. A number of types have been studied to determine to what degree each meets these requirements. From several mechanical, hydraulic, and electrical methods considered, one mechanical and one hydraulic have been selected for further analysis.

The need for the determination of the effect of fuel consumption on engine performance in flight has led to the development of an experimental Venturi type fuel flow meter. This flow meter has been used on several flights with satisfactory results. A more serviceable flow meter embodying the same principles is now being designed.

*Completed investigations.*—Four investigations have been completed from last year. Three of these investigations were on problems directly pertaining to supercharging and the other on a problem incidental to supercharging.

The first investigation dealt with preliminary flight testing of the N. A. C. A. Roots type aircraft engine supercharger. The results show that the Roots type supercharger is inherently adaptable to commercial airplanes and to a number of military and naval airplanes, because of its low weight, mechanical simplicity, high efficiency, and low power requirements at moderate altitudes. Supercharging increased the ceiling, improved the climbing performance, and increased the air speed so that for a large range of altitudes it was higher than the normal sea-level maximum. The engine showed no detrimental effects which could be attributed to supercharging. This material has been prepared for publication.

The second investigation was conducted on a Wright E-4 and a Liberty-12 engine. The results obtained show the effect of high inlet air temperatures on power. In these tests the carburetor air temperature was varied from 45° to 180° F., and the speed from 1,400 to 1,800 revolutions per minute. Two fuels were used, domestic aviation gasoline and a mixture of 30 per cent benzol and 70 per cent gasoline. The blended fuel gave 5 to 6 per cent more power at the speeds giving maximum volumetric efficiency than did the domestic aviation gasoline. For a blended fuel the relation between temperature and power is linear. The indicated power decreases at a much faster rate with increase in temperature than that given by the square-root relation. For small variations in temperature, as occur for changes from one season to another, the square-root relation is sufficiently accurate, but where the change of temperature is very large and greater accuracy is desired, the temperature correction to be applied should be determined by testing the engine. The results of these tests have been prepared for publication.

The third investigation completed was on the comparative laboratory performance of three sizes of Roots superchargers. Compared on the basis of air delivered, the performance characteristics are similar except for the smaller superchargers, for which the power requirements are higher because the power required increases more rapidly than the speed. The difference between the actual and the theoretical power required to deliver the air in quantities and at pressures encountered in the range of ordinary supercharged flight varies with the speed raised to the 2.5 power. The ratio of discharge air temperature  $T_2$  to the inlet air temperature  $T_1$  depends upon the speed and may be evaluated by raising the ratio of the discharge pressure  $P_2$  to the inlet pressure  $P_1$  to the  $n-1$  divided by  $n$  power, and multiplying this result by a constant  $C$ . The value of  $n$  in this relationship increases from 1.36 for an impeller length of 4 inches to 1.53 for an impeller length of 11 inches. The value of  $C$  varies from 1 at zero speed to 1.05 at 6,500 revolutions per minute. The results of these tests have been prepared for publication.

The fourth investigation completed includes the tests on a TS and a UO-1 airplane equipped with an air-cooled engine and an N. A. C. A. Roots type supercharger. In these tests the absolute ceiling of the UO-1 was increased from 19,400 to 32,000 feet by supercharging, and the time of climb to 16,000 feet was reduced 50 per cent. The average cylinder-head temperature obtained on several unsupercharged and supercharged flights was 325° and 470° F., respectively. The engine showed no detrimental effect that could be attributed to supercharging.

*ENGINE ANALYSIS.—Fuel vapor pressure.*—The performance of a high-speed oil engine is largely dependent upon the rate of vaporization of the fuel charge within the combustion chamber. The vapor pressure of fuels has been fairly well established up to approximately 300° C. but for temperatures greater than this the available data are incomplete. An investigation was therefore undertaken to determine the vapor pressures and temperatures of several fuels up to their autoignition temperatures. From the results of this investigation, the temperatures required to force rapid vaporization of these fuels in an engine cylinder could be determined.

The vapor pressures and temperatures of six fuels, various mixtures of these fuels, a lubricating oil, and water were determined up to 900° F. and 5,000 pounds per square inch pressure. A considerable amount of test data has been taken which indicates the stability and instability of the liquids tested. The test data are being analyzed and corrected for change in volume of the apparatus due to the high fuel vapor pressures and temperatures and to the diminishing quantity of the liquid fuel in the bomb of the test apparatus. The final results will be incorporated in a report for publication.

*Analysis of cycle efficiency.*—The performance of high-speed oil engines for aircraft is dependent upon the overall efficiency (which include cycle, combustion, volumetric, mechanical, and cooling efficiencies), maximum cylinder pressure, and the maximum overhaul period. Aircraft engine performance should be such that maximum power per pound engine weight, minimum fuel consumption per horsepower per hour, and maximum reliability are obtained.

The engine cycle that should be used in high-speed oil engines for aircraft is the dual cycle, a combination of constant volume and constant pressure combustion. Such a cycle would decrease the weight per horsepower and increase the reliability for the same power output obtained with the Otto cycle. Since it is important to compare various engines as to the efficiency with which the fuel is burnt and so compare engine designs, it is necessary to know the cycle efficiencies at which they operate.

A theoretical investigation is being made on the effects of compression pressure, air available for combustion, temperature of the induced air, temperature and pressure of the residual exhaust gases, explosion pressure, and point of cut-off on the efficiency of the dual cycle. This work involves calculations for the pressures and temperatures at all points on the indicator card, and these in turn require the use of the specific heats of gases for constant pressure and volume up to the highest temperatures of combustion, the Joule-Thomson effect, volumetric efficiencies versus compression ratio, chemical composition and weight of the working mixture at all points of the cycle, quantity of fuel required for various points of cut-off, and other factors. The completed results of this work will enable the rapid determination of the cycle and combustion efficiencies of an engine when the usual test data are known.

Calculations have been made to determine the effects of high residual exhaust-gas temperature on the pressures and temperatures throughout the cycle for a compression ratio of 11. The results show that an increase of 300° F. in the temperature of the residual exhaust gases increased the temperatures and pressures throughout the cycle only slightly. The maximum increase in temperature obtained at the end of the suction stroke was 4° F. The pressure increase was 0.05 pounds per square inch.

Experiment and theoretical analyses have shown that the specific heat of gases varies with the temperature and pressure, especially with the temperature. It is therefore of importance in calculating the amount of work done on the compression and expansion stroke of an oil engine that the exponent for adiabatic changes of state in the fundamental equation for compression and expansion should be accurate for the temperature involved.

Calculations of pressures and temperatures have been made at several points on a compression curve, first by using a constant value for the exponent, and second by using a varying value for the exponent for adiabatic changes of state to determine the extent of error involved by using the constant value. The results show that the negative work done by using a constant exponent in the calculations was less than that obtained by using a varying exponent, although the difference was small. The greatest variation in pressure was of the order of 0.5 per cent. This result was expected on account of the small variation of the exponent with temperature for the compression stroke. Since the value of the specific heat of gases increases with temperature it is expected that on the expansion stroke the result of similar calculations will show an appreciable error in the work done, because of the higher temperatures involved.

A method of calculating the theoretical cycle efficiency of an oil engine has been practically completed. The data required for this work are the compression ratio, volumetric efficiency under power, temperature of the inlet air, temperature and pressure of the residual exhaust

gases, maximum cylinder pressure, and bore and stroke of the engine. The completion of this work will give a method for calculating the theoretical cycle and combustion efficiencies of an oil engine.

An investigation of the specific heats of the gases of combustion for temperatures up to 3000° C. is in progress. It was found by evaluating and plotting a large number of empirical formulae developed by various investigators that there was a wide discrepancy in the results. The investigation has shown that the specific heats of the gases of combustion may be obtained by three methods—by considering the theoretical heat content of the molecule due to its translational, vibrational, and rotational energy, and by experimental methods involving the study of the velocity of sound and explosion. An attempt is being made to correlate the theoretical and experimental data for use in engine calculations.

*Chromium-plated pistons.*—Four Liberty pistons have been chromium-plated and tested to determine the wearing quality of chromium plating under both motoring and power conditions. The chromium plating on the crowns of the four pistons tested showed no material change, which indicates that temperature alone probably has little effect on the chromium plating. The excessive wear of the chromium plating on the piston skirt when under power in comparison to that when being motored, indicated that the failures of the chromium plating were apparently caused by the formation, growth, and breakage of blisters due to the lack of bond between the aluminum and chromium, and to the combination of rubbing and light and medium piston slap.

#### BUREAU OF STANDARDS

*Supercharging of aircraft engines.*—Tests have been made in the altitude laboratory of a Curtiss D-12 engine equipped with a gear-driven centrifugal supercharger, installed between the carburetor and the intake manifold. This supercharger is designed for low-altitude work and for an engine speed of 2,000 revolutions per minute, its critical altitude is about 7,500 feet. Two types of manifold were used and about 5 per cent more power was obtained at all altitudes with one type of manifold than with the other. Up to the rated altitude, the power output with this supercharger and with the manifolds giving best distribution was from 5 to 10 per cent less than that obtained with the same engine under ideal supercharging conditions (i. e., with no power required to drive the supercharger). These tests were requested by the Army Air Corps and covered conditions corresponding to altitudes from sea level to 25,000 feet.

*Phenomena of combustion.*—The study of the gaseous explosive reaction by means of the constant-pressure bomb (soap bubble) has been continued and the thermodynamic as well as the kinetic possibilities of this method have been pointed out in several journal articles. That reaction velocity is proportional to the molecular concentration of the reacting gases has been verified for known mixtures of (1) carbon monoxide and methane with oxygen, and (2) carbon monoxide and hydrogen with oxygen. The effect of inert gases (nitrogen, helium, or carbon dioxide) on the carbon monoxide-oxygen reaction and on the methane-oxygen reaction has also been studied. A report to be published by the National Advisory Committee for Aeronautics shows that the effect of an inert gas on the reaction rate may be accounted for by an additive term, directly proportional to the concentration of the inert gas. The proportionality constants for different inert gases evidently depend on their thermal properties.

*Combustion in an engine cylinder.*—This project is concerned with obtaining information of a fundamental nature on the factors which influence combustion in actual engine cylinders. During the past year the effect of combustion time on engine performance has been analyzed on the basis of certain simplifying assumptions and the results compared with deductions from actual indicator cards. Technical Report No. 276 presents this discussion.

*Automatic altitude control.*—Runs were made with the Curtiss D-12 engine in the altitude laboratory to determine the proper opening of the carburetor control valve for various altitudes up to 25,000 feet. An automatic valve designed from the data thus obtained gave a constant fuel-air ratio from 5,000 to at least 20,000 feet. This work was done for the Army Air Corps.

At the request of the Navy, work has been started on the design of an automatic carburetor altitude-control device for the same engine, utilizing the multiplied pressure pump described in Technical Note No. 108 of the National Advisory Committee for Aeronautics.

*Gaseous-fuel carburetor.*—At the request of the Navy, an experimental gas carburetor was designed and data have been obtained on the relative performance of a given engine at various speeds and loads on aviation gasoline, on city illuminating gas, and on mixtures of the two. The results obtained will probably be used in the development of a gas carburetor for actual flight test on an airship engine. The object in view is the possibility of increasing the cruising range of lighter-than-air craft by the employment of natural gas or illuminating gas as an auxiliary fuel.

*Fuels for high-compression engines.*—The testing of fuels and fuel dopes in the single-cylinder Liberty engine has been continued. None of the fuel dopes submitted was found to affect power, economy, or antiknock value appreciably. While cracking and increased volatility both tend to raise the antiknock value of gasolines made from a given crude oil, the improvement due to cracking is often much less than the difference between straight-run gasolines from different crudes.

At the request of the Navy, work has been done on the development of a simple laboratory device for comparing the antiknock characteristics of aviation gasoline. An experimental bomb was built which had approximately the internal dimensions of the combustion chamber in a Liberty engine cylinder. This bomb gave average results which appeared to rate several fuels in the same order as does the routine engine test of the Bureau of Standards. However, successive observations with a given fuel under apparently identical conditions often showed considerable variation and a second bomb, having the same volume but different dimensions, is to be compared with the first bomb as regards reproducibility of results. Since the bomb test is rapid and requires only a small sample of fuel it has obvious advantages, provided that it can be shown to give consistent results which are uniformly in accord with the performance of fuels in aviation engines.

*Lubrication under starting conditions.*—Measurements of the rate of flow of about 35 commercial lubricating oils through the oil passages of a Wright J-4 engine, mounted in a cold chamber and slowly motored over, have been completed. These and other experiments on the flow of aircraft-engine oils at low temperatures form the basis of an extensive report now in preparation. The first conclusion of this work is that neither the pour point of an oil nor its viscosity at 210° F. is sufficient to determine its performance in the engine at temperatures below the ice point.

*Starting of internal-combustion engines.*—The analysis of laboratory data on fuel volatility and engine starting tests has made it possible to specify the fuel requirements for engine starting in terms of the usual A. S. T. M. distillation curve. It was also shown by bomb experiments with known mixtures of gasoline vapor and air that cracked gasolines do not differ in starting ability from straight-run gasolines of like distillation characteristics.

#### NEW ENGINE TYPES

The most striking developments of the year have been the advances made in air-cooled engines. These have included improvements in performance, increases in reliability, and reductions in the cost of maintenance. During the year no radical developments in the form of unconventional types of engines have appeared, with the exception of the Fairchild "Caminez" engine, which is now on the market.

The Fairchild "Caminez" engine is a 4-cylinder radial air-cooled engine, using a cam-type drive in place of the conventional crank shaft. The engine is the result of a number of years of intensive development, first by the engineering division of the Army Air Corps and later by the Fairchild Co. This engine is rated at 135 horsepower at 1,050 revolutions per minute and weighs approximately 340 pounds without starter and propeller hub.

Both the Bureau of Aeronautics and the Army Air Corps have assisted in the further development of air-cooled engines. The Army Air Corps is particularly interested in the

development of the Curtiss "Hex" engine, which is a 600-horsepower radial air-cooled engine having two banks of cylinders. This particular arrangement is the result of an effort to decrease the overall diameter and to eliminate the counterweight on the crank shaft.

The Army Air Corps has continued the development of the inverted air-cooled Liberty engine. The experimental engines of this type, built by the Allison Engineering Co. under the supervision of the Air Corps, have completed their tests and a number have been procured by the Air Corps for service use.

As an outgrowth of the air-cooled Liberty engine the Air Corps is sponsoring the development by the Wright Co. of a 12-cylinder air-cooled "V" engine of approximately 600 horsepower. The Air Corps is also sponsoring the development of a 24-cylinder "X" type engine which is being constructed by the Allison Engineering Co. This engine is expected to develop approximately 1,400 horsepower.

*Air-cooled engines.*—There are now available service-type air-cooled engines which can be substituted for the water-cooled aircraft engines of corresponding power, with the exception of the Packard 800-horsepower engine.

The air-cooled engines that have been developed are of two general types, the radial and the "V" type. Of the radial types the most prominent is the 9-cylinder Wright "Whirlwind" model J-5 engine. This engine is a further development of the J-4 type. It has a greatly improved cylinder construction and has fully inclosed valve gear. It also is equipped with a new "Eclipse" concentric impulse starter. The engine is in extensive use in military and commercial services.

The Wright "Cyclone" R-1750 type is a larger 9-cylinder radial air-cooled engine which has been flight-tested by the Navy Department and is still undergoing service tests. This engine is rated at 525 horsepower at 1,900 revolutions per minute.

The Pratt & Whitney "Wasp" 9-cylinder radial engine rated at 410 horsepower at 1,900 revolutions per minute has passed its service tests and is now in production. This engine is now considered standard equipment on a number of Navy service-type airplanes and has given a most satisfactory performance.

The Pratt & Whitney "Hornet," a 9-cylinder radial air-cooled engine, having a displacement of 1,690 cubic inches, is expected to develop 500 horsepower at 1,800 revolutions per minute. This engine was designed for use in heavy-duty types of aircraft and is now in the experimental development stage.

*Water-cooled engines.*—Continued development, as a result of service use, has been made on the Curtiss V-1550 engine, which is a further development of the Curtiss V-1400 and the very successful Curtiss D-12 engines. This development has been sponsored by the Army Air Corps. The new engine will develop 600 brake horsepower at 2,400 revolutions per minute and is available in both direct-drive and geared types. The weight of the direct-drive type is approximately 740 pounds. This engine has completed the experimental development stage and is now being given service tests.

The Packard 1A-1500 engine is being further developed as a result of experimental and service tests by the Army Air Corps. A new type, the 2A-1500, has successfully passed the experimental stage at a rating of 600 horsepower at 2,500 revolutions per minute. The 2A-1500 engine is made in the inverted direct-drive type and in the upright geared type. The large Packard 2500 engine has been further developed, and the latest type, the 3A-2500, is expected to develop 1,000 horsepower at 2,300 revolutions per minute. This engine has also been specially designed for use with superchargers.

*Superchargers.*—Superchargers have now passed from the experimental development stage to service use. The Roots type and the centrifugal type superchargers have been adapted successfully to the radial air-cooled engine, and superchargers of both types are in experimental development on the water-cooled types of engines in service.

## REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

## ORGANIZATION

The present organization of the Committee on Materials for Aircraft is as follows:

Dr. George K. Burgess, Bureau of Standards, chairman.  
 H. L. Whittemore, Bureau of Standards, vice chairman and acting secretary.  
 Lieut. R. S. Barnaby, United States Navy.  
 S. K. Colby, American Magnesium Corporation.  
 Henry A. Gardner, Institute of Paint and Varnish Research.  
 Dr. H. W. Gillett, Bureau of Standards.  
 Prof. George B. Haven, Massachusetts Institute of Technology.  
 Zay Jeffries, Aluminum Co. of America.  
 J. B. Johnson, matériel division, Army Air Corps, Wright Field.  
 George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).  
 Capt. H. C. Richardson, United States Navy.  
 G. W. Trayer, Forest Products Laboratory, Forest Service.  
 Starr Truscott, National Advisory Committee for Aeronautics.  
 Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.

## FUNCTIONS

Following is a statement of the functions of the committee on materials for aircraft:

1. To aid in determining the problems relating to materials for aircraft to be solved experimentally by governmental and private agencies.
2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding investigation of materials for aircraft in progress or proposed.
4. To direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development. Much of the research, especially in the development of light alloys, must necessarily be conducted by the manufacturers interested in the particular problems, and both the Aluminum Co. of America and the American Magnesium Corporation are represented on the committee. In order to cover effectively the large and varied field of research on materials for aircraft, four subcommittees have been formed, as follows:

*Subcommittee on metals:*

Dr. H. W. Gillett, Bureau of Standards, chairman.  
 Zay Jeffries, Aluminum Co. of America.  
 J. B. Johnson, matériel division, Army Air Corps, Wright Field.  
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).  
 Starr Truscott, National Advisory Committee for Aeronautics.  
 H. L. Whittemore, Bureau of Standards.

*Subcommittee on woods and glues:*

G. W. Trayer, Forest Products Laboratory, Forest Service, chairman.  
 H. S. Betts, Forest Service.  
 George W. Lewis (ex officio member).  
 H. L. Whittemore, Bureau of Standards.

*Subcommittee on coverings, dopes, and protective coatings:*

Henry A. Gardner, Institute of Paint and Varnish Research, chairman.  
 Dr. W. Blum, Bureau of Standards.

*Subcommittee on coverings, dopes, and protective coatings—Continued.*

Warren E. Emley, Bureau of Standards.  
Prof. George B. Haven, Massachusetts Institute of Technology.  
Isadore M. Jacobsohn, Bureau of Standards.  
George W. Lewis (ex officio member).  
P. H. Walker, Bureau of Standards.  
E. R. Weaver, Bureau of Standards.

*Subcommittee on Aircraft Structures:*

Starr Truscott, National Advisory Committee for Aeronautics, chairman.  
Charles Ward Hall, Hall-Aluminum Aircraft Corporation.  
Lieut. Lloyd Harrison, United States Navy.  
G. W. Lewis (ex officio member).  
Charles J. McCarthy, Chance Vought Corporation.  
L. B. Tuckerman, Bureau of Standards.  
John E. Younger, matériel division, Army Air Corps, Wright Field.

Most of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics.

The Bureau of Aeronautics and the matériel division of the Air Corps, in connection with the operation of tests in their own laboratories, apportion and finance research problems on materials for aircraft to the Bureau of Standards, the Forest Products Laboratory, and the the industrial research laboratories.

## MEETINGS OF THE COMMITTEE

As in past years the committee held several meetings during the year. The corrosion of the light alloys continues to be one of the subjects of great interest and has received much attention at each meeting. At the meeting which followed the second general aircraft conference at the Langley Memorial Aeronautical Laboratory Mr. E. H. Dix of the Aluminum Co. of America read a paper describing a new corrosion-resisting light alloy product of that company called "Alclad." This material consists of a sheet of aluminum alloy having a layer of very pure aluminum on each side. It appears to have remarkable resistance to corrosion. This paper has been issued by the committee as a technical note.

## SUBCOMMITTEE ON METALS

*Intercrystalline embrittlement of duralumin.*—The subcommittee on metals has continued its experimental work on the study of the causes and prevention of intercrystalline embrittlement of duralumin. Corrosive attack starting at the surface and penetrating between the crystals may notably embrittle duralumin without the surface showing evidence of the extent of the attack below the surface. This embrittlement has been met in service to an extent sufficient to limit materially the application of duralumin in construction of aircraft for which long life is necessary, and has made it imperative that the deterioration be prevented.

During the period within which the problem has been studied sufficient advances have been made so that it is no longer a question whether or not the attack can be prevented, but it is instead merely a question of which one of several effective methods should be chosen in a particular case.

The laboratory methods of accelerated-corrosion testing chosen to indicate the propensity of the alloy toward intercrystalline embrittlement have so far shown good agreement with exposure tests.

The behavior of nonmetallic protective coatings is not so readily determined by laboratory tests and final choice among such coatings must await the completion of exposure tests.

The chief effective precaution, other than the use of some protective coating, is to quench the duralumin rapidly rather than slowly; that is, in cold water rather than in hot water or oil, since the former procedure gives material much less susceptible to embrittlement than the latter.

Age-hardening at room temperature rather than accelerated aging at elevated temperature also favors resistance to intercrystalline attack. These heat-treatment factors have much more to do with corrosion resistance than do any variations in chemical composition likely to be met commercially.

While duralumin suitably heat-treated is improved in corrosion resistance, embrittling corrosion is not thereby wholly avoided. Hence protection of the surface is also required.

It was stated in last year's report that protection of duralumin by a surface coating of pure aluminum was one of the surest methods. Further experiment and the results of exposure tests corroborate this, and justify the present conclusion that it is the most effective method yet available. The lead offered by the previous investigations of the subcommittee upon aluminum-coated duralumin has been followed by an American producer of duralumin, and duralumin sheet with an integral coating of aluminum on each side is now commercially available, so that this expedient is not one of merely academic interest, but is ready for application in practice. While the strength of the commercial aluminum-coated duralumin is not quite as high as that of plain duralumin, the initial strength and ductility will be retained with little loss so that after a period of service the initially weaker material will be the stronger.

The aluminum-coating process has not yet been commercially applied to tubing so that other methods of protection still need consideration. It is also advisable to make assurance doubly sure by using a nonmetallic protective coating over the aluminum surface since the aluminum coating, while not subject to the intercrystalline type of attack, is, like all other aluminum and aluminum alloys, subject to the less dangerous type of general corrosion whose advance is visible on the surface.

Nonmetallic protective coatings of the aluminized-varnish or bitumastic type, which have heretofore been largely used as protecting coatings, cling well on a mat surface, and poorly on a smooth metal surface. Hence where these coatings are to be used preliminary anodic treatment in chromic acid to produce the "anodic coating" or a chemical treatment producing a similar surface is advisable. The anodic coating in itself offers some protection but not enough to be a real solution. As a base for adherent coatings it is, however, of distinct value.

The chief trouble with coatings of the varnish type is their tendency to become brittle and to check and crack off. Flexibility of the coating is a very real advantage. Since any completely moisture-repellant coating which will "stay put" will defeat corrosion, covering the anodic coating with oil or lanolin gives very effective protection as long as the oil film remains. Oiled anodic coatings are finding much use here and abroad. They do not add as much weight as coatings of the varnish type and if the oil film is kept intact by periodic renewal offer much improved protection compared with a bare surface. Such coatings have some tendency to collect dirt, which may be decreased by the use of fairly thick coatings dusted with aluminum powder. A drawback to the oil coating is that visual inspection does not readily show whether the film is intact or not, so that recoiling on a definite schedule should be resorted to.

A recent development in the line of a flexible, water-repellant coating applicable to duralumin is a rubber cement which will stick tenaciously to metal and hence may be applied without previous anodic coating. The bare rubber cement breaks down rapidly in the atmosphere and by itself offers little real promise. Mixture of aluminum powder with the cement, or merely dusting aluminum powder on the tacky surface and brushing it down, raises the resistance of the cement to atmospheric influences almost immeasurably. While exposure tests of such a coating on duralumin have not yet progressed far enough to warrant final conclusions, the aluminized rubber coating deserves extended trial. It even offers promise for the protection of magnesium, a matter to which the subcommittee has given considerable attention and on which it can report continued activity and interest by producers of magnesium.

The foregoing shows that not only may duralumin itself be improved in corrosion resistance by suitable heat treatment, but that a variety of effective protective coatings are available which are applicable to most aircraft parts. Pontoons and tubing (especially the protection of the interior of tubing) still offer problems. It would appear that aluminized rubber coatings deserve trial on pontoons. Pending the availability of aluminum-coated duralumin tubing,

attention is being paid by the subcommittee, together with the subcommittee on aircraft structures, to high-chromium and other corrosion-resistant steel tubing. The fabrication and welding of such tubing appears feasible and may be expected to be better understood in the near future.

More advance has been made on the engineering angles of the protection of duralumin than on the clearing up of the mechanism by which embrittlement takes place, though unremitting effort has been put on the study of the cause of embrittlement. Metallographic and X-ray methods are being applied. The phenomenon of asterism, shown by "pin-hole" X-ray photographs of embrittled duralumin is being studied, but so far it appears that, while asterism usually accompanies embrittlement, intercrystalline attack can occur without asterism. Definite location of the cause of asterism may help in determining the cause of embrittlement.

There is some reason to believe that duralumin under the stresses of service is more subject to embrittlement than in unstressed exposure. On account of the importance of appraising the validity of exposure tests, experiments are under way to study the effect of both static and repeated stresses upon the progress of intercrystalline corrosion. Apparatus for this has been designed and constructed and the experiments are under way.

The exposure tests which will tend to verify or disprove the tentative conclusions given above as expressing the facts as far as they are at present known to the subcommittee are being continued, some 1,700 specimens being under exposure test, their properties being determined at appropriate intervals.

*High-speed fatigue testing.*—Continued work with the high-speed fatigue-testing machines has shown that the discrepancy between the results from the high-speed machines and the previously used crank-driven machines is not accounted for by incipient corrosion of the specimen. Check tests run in the old machines duplicated the previous results.

The major problem to be solved is the determination of the cause of this discrepancy. It may be due to adventitious stresses caused by the type of support, although the theoretical investigations made seem to preclude this. It seems more probable that it is due to an actual change of fatigue properties with the frequency of application of the load. With this question still unsettled it has not seemed desirable to start tests on magnesium and steel specimens as it is ultimately intended to do.

The investigation has been continued on the following lines:

(a) The method of supporting the specimen in the present air-driven machines has been changed from a pivot support to an air-jet support, thus freeing the specimen wholly from any possible longitudinal restraint, due to the pivots, which might introduce adventitious stresses. The machines with the new type of support are running smoothly but have not been in operation long enough to give definite results.

(b) Preliminary experiments and computations have been made on an electrically-driven machine with loaded specimens in order to close the gap in frequencies (200 per second to 20 per second) between the two types of machines. No conclusive results have as yet been obtained.

#### SUBCOMMITTEE ON WOODS AND GLUES

The Forest Products Laboratory of the Department of Agriculture conducts practically all the investigations on the application of woods and glues to aircraft construction. These investigations are undertaken at the request of the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, or the National Advisory Committee for Aeronautics. Some of the more important investigations completed during the past year or now in progress are outlined below.

*The lateral buckling and twisting of deep beams.*—The Bureau of Aeronautics, Navy Department, realized that it would be highly desirable to know the maximum load which could be carried by a wing beam under any condition of loading and fixity. Accordingly there has been carried on for some years a series of studies on the strengths of beams for the purpose of giving information to the designer. These have included researches into the behavior of continuous beams and into the design of detailed parts of various types of beams.

According to the commonly applied beam formulæ the strength of a beam increases more rapidly with depth than with thickness. Hence in aircraft, where weight is such an important item, designers usually use comparatively deep and narrow wing beams. The ratio of depth to breadth has usually been kept within certain arbitrary or conventional limits, since it is well known that a beam much deeper than wide may buckle laterally and twist before it will break by bending in a vertical plane. As a matter of fact there is for each condition of loading and support of a beam a critical buckling load just as there is a critical Euler load for a column. Under small loads a beam behaves according to the action assumed in the beam formula, but when the critical load is reached it buckles sideways, twists, and fails. Beyond the elastic limit, owing to a reduced modulus of elasticity, this twisting and buckling would cause a reduction in the ultimate load of practically all airplane wing beams of conventional size unless they were supported against it. When two wing beams are tied together with ribs lateral buckling may or may not be prevented. If the ribs are efficiently designed for their own loads alone they will have no reserve resistance for the extra load which any tendency of the beam to buckle would produce. On the other hand, if they are just a little stronger than necessary they may help to hold a quite deep beam in line until its maximum load is reached.

A study of this phenomenon was undertaken, using wood, which seemed to offer the best possibilities as test material because of the ease with which it could be worked into different shapes. So far as is known, very little experimental work had previously been done, although the problem of lateral stability had been investigated mathematically and several useful formulæ had been obtained, notably those by S. Timochenko.

The mathematical analysis by Timochenko was checked experimentally and found to be correct within the limits of accuracy of the experiments. Each of Timochenko's formulæ calls for certain constants dependent on the material. From this investigation have been derived the constants for stresses both within and beyond the elastic limit.

*The bearing strength of wood under steel bolts.*—This investigation covers quite completely such features of design as allowable bearing strength of wood under bolts subjected to a load acting at any angle to the grain, the allowable distance between bolts, the influence of cross bolts, the combined action of bolts of different diameters, the allowable bearing stress under washers, serviceability of different styles of fitting blocks, etc.

The first of a series of previous investigations of a generally similar character dealt with solid bolts and a condition of loading where the pull on the bolt was parallel to the grain of the wood. A second dealt with hollow bolts under the same conditions of loading, while a third covered the case where the pull was at an angle to the grain and in the plane determined by the grain and the axis of the bolt. This report covers the condition in which the axes of the bolts are perpendicular to the grain of the wood but not in or parallel to the plane determined by the line of action of the force and the grain of the wood.

The report covers many details involved in the design of fittings to be attached to wooden spars, including the spacing of the bolts, the use of bolts of different sizes, the fitting of bolts in laminated beams, and the design of fitting blocks for box beams, and gives certain factors to be applied to the design formulæ which have been used heretofore.

*Preparation of manual for inspectors of aircraft wood and glue.*—This work consisted of a compilation and digest of much of the perennially useful material developed in aircraft studies by the Forest Products Laboratory in the last 10 years and was done for the Bureau of Aeronautics, Navy Department. Separate chapters give descriptive material or instructions concerning inspection and process work under the following headings:

Structure and characteristic defects of wood.

Strength of wood.

Seasoning processes.

Steaming and bending.

Glues and gluing.

Common stains and decays in wood.

Identification of woods.

Specifications.

This manual, while primarily intended for the use of inspectors connected with the procurement of naval aircraft material, is expected to be of service to inspectors on similar work for the Army Air Corps or the Department of Commerce and for individual manufacturers. It also offers promise as a text for use in the instruction of aeronautical engineers, wood technicians, and mechanics who contemplate working in aircraft woods. This manual is now being printed by the Government Printing Office and will be available at a moderate cost for unrestricted distribution in this country.

*Increasing durability of glued joints.*—This work comprises an investigation into the effect upon mold formation and chemical dissolution (such as hydrolysis) of preservatives used with glues for aircraft use. The investigation has covered the study of the effects of application of various preservatives to the glue before use and also of the steeping of the completed joint in preservative material. No compound has been found to date whose addition to glue entirely inhibits molding. Beta naphthol and creosote when added in considerable quantities to water-resistant casein or animal glue and sodium chromate added to cold-pressed blood glue materially reduce molding and increase the durability of this glue film without affecting the other important properties of the glues beyond practical limits. They add considerably to weight, however.

*Survey of gluing practice at naval aircraft establishments and contractors' plants.*—At the request of the Bureau of Aeronautics, Navy Department, an inspection was made of the gluing practice followed at a number of naval aircraft establishments and contractors' plants. Individual inspection reports on the various plants visited were submitted and a final summary and report was also prepared. Many specific recommendations and suggestions were made to accompany a number of the general recommendations.

*Permanence of glues.*—Continued study has been devoted to the methods of handling casein glues in manufacturing processes. One of the most interesting features is the behavior of the glue during the period between mixture and final pressing. It is of great advantage to have a glue which retains its workability during this period but which does not require too great a time for setting after the working period is over. Accordingly experiments have been made to determine the influence of various factors on the viscosity of the glue during this period.

#### SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS

*Gas cell fabrics.*—The work on the experimental gas cell fabrics made of materials intended to supply a substitute for goldbeater's skin has encountered difficulties due to the sensitiveness of these materials to outside influences. Both of the two types which have been developed to a point where they appear to have real promise are applied to a rubberized fabric having a very thin coat of spread rubber. The influence of the thin layer of rubber, and its compounding and curing, on one type was not suspected until difficulties were encountered due to variations in these factors. It was found that the material used in the original experiments was entirely satisfactory, but that a considerably larger quantity which was intended for use in a production order, had a composition and curing much different from the original. This resulted in the production of gas-cell material much inferior to the earlier samples.

The cause of the trouble was quickly located, but it was necessary to spend considerable time in making certain that a new supply of rubberized cloth should not possess the objectionable qualities found in the first one. The work is continuing with the confident expectation of ultimate success.

In connection with the development of the type of material using cellophane, the manufacture of a gas cell from fabric using the cellophane with high glycerine content has been delayed by the inability to obtain this material as promptly as was desired. It apparently is a special product and not produced regularly. When larger quantities are required it will undoubtedly be available as may be needed.

A most encouraging development has been the development of interest in this problem by one of the manufacturers of the raw materials used in the substitute for goldbeater's skin. This promises to lead to the taking over of the problem by them, when with the facilities available in their organization it should require only a comparatively short time before a satisfactory substitute fabric is available. This would be an arrangement very much to be desired, as it would

then be possible to purchase the fabric in yardage from the manufacturer and assemble the gas cells very much as is the case with rubberized fabric.

*Coatings for duralumin to prevent corrosion.*—While the anodic treatment apparently confers some degree of protection against corrosion in atmospheres which do not contain salt or other alkaline constituents, it certainly is relatively inefficient near the sea. Consequently the value of the process has been somewhat doubted. However, it is plain that the anodic treatment does improve the surface of aluminum alloys very much whenever it is intended to apply further coatings. Apparently a layer of infinitesimal thickness is produced which affords an almost ideal surface for the retention of grease or other coatings. Remarkably encouraging results have been reported from the use of the anodic treatment followed by a lanolin coating, or a grease, in which a proportion of aluminum powder has been mixed. Instead of the greasy surface which would naturally be expected, the coating results in a comparatively hard surface which does not easily rub off.

No paint and varnish coats which have been tried have been found to give any degree of protection comparable to that from the anodic treatment plus grease or to that conferred by the bituminous coatings. However, it has been definitely established that the bituminous paints must be given a light color by some pigment, preferably aluminum powder, or they will break down in the sunlight. Where not exposed to the sunlight this light color is not required.

The process by which a thin layer of gum rubber is built up on the surface of the material has been perfected to an extremely high degree. By the addition of powdered aluminum as a pigment the resistance to the deteriorating effect of sunlight has been much increased. Coatings applied by this method are extremely adhesive, and since they are repellent to water the degree of protection conferred is of a high order. However, the thickness of the coating which is required to give adequate protection is such that a distinct increase in weight is involved.

In the last report of this committee reference was made to the high degree of protection conferred by a thin coat of pure aluminum. It was then referred to as applied by means of the metal spray gun. The Aluminum Co. of America have now succeeded in producing a thin coat of very pure aluminum forming an integral part of the sheet of duralumin. Duralumin sheets protected on both sides by this method have shown remarkable resistance to corrosion, and the protection extends to uncoated duralumin, in the form of rivets, or bare spots of about one-half inch diameter, on the sheet. Although the final verdict can not be given without service tests, all the accelerated tests indicate that this material is the most successful in its protection which has so far been developed. If material of this character is anodically treated and then greased it is believed that the protection may be considered to be practically perfect.

The exposure tests on protective coatings for duralumin are still under way, and while some coatings have already broken down and others show signs of beginning to break down the tests are not yet completed. This was one of the purposes of making these tests, as it was hoped to obtain a scale by which to measure the results of accelerated corrosion tests.

The nitrocellulose lacquers for the protection of small metal fittings have come into wide use and afford a very useful method of rapidly applying a moderately effective protective coating by hand. With these, however, it is necessary to maintain the coating by constant inspection.

With the development of the method of protecting the aluminum alloys by means of a pure aluminum layer forming an integral part of the sheet it would appear that a very satisfactory solution for this problem has been obtained. It is confidently expected that this material will make possible the widespread use of duralumin in many places where it has heretofore been regarded with suspicion. By combining the pure aluminum coating with other methods, as described, the degree of protection can certainly be increased to far beyond anything which has been known heretofore. With the continuing development of this material and its introduction in the form of sections and tubing protected on both surfaces, as may be expected, aluminum alloys should become one of the most used materials in aircraft.

*Airplane dopes.*—During the past year semipigmented dopes have come into general use. These are nitrate dopes in which pigment has been incorporated in quantity approximately 25 per cent of that in the usual pigmented dopes. The doping schemes with these dopes contemplate the use of semipigmented dopes exclusively, no clear dopes being used.

Surfaces doped with semipigmented dope which have been in service for a considerable period of time have shown a marked increase in durability over surfaces using the old doping schemes where clear dopes were used and protected with a pigmented dope and pigmented varnish. Specifications covering this new material are being prepared by both Army and Navy.

Experiments on airplane dopes are still being conducted at the Naval Aircraft Factory. These include the older forms and the newer semipigmented dopes. An effort is also being made to develop some quantitative method for determining the tautness of a doped panel and some method for estimating the actual durability from an accelerated test. The Barnaby & Freymoyer tautness meter referred to in last year's report has now been superseded by the Mullen paper tester. The Naval Aircraft Factory is investigating the application of this tester and compiling coefficients for use in the interpretation of the results obtained with it.

*Substitute for silk parachute cloth.*—An American-made silk cloth to be used in place of the imported silk cloths which have been used in the manufacture of airplane parachutes has been developed and is now being incorporated in a production order.

The problem of finding a substitute for silk for this purpose has been attacked along the lines of treating cotton yarn by modified mercerization and doping processes. Gains in strength and elasticity as shown both in the yarn and in trial weavings using the treated yarns as the filling for the cloth have been accomplished.

The problem has now been shifted from the laboratory to a production scale. The difficulties experienced in the laboratory development work suggested the advisability of dividing the work into three different sections: Yarn treatment, cloth treatment, and a complete mill organization and finishing treatment.

In connection with the yarn treatment it has been found that domestic fine yarns with the desired properties are difficult to obtain. Most of the yarn used in the early work was made in England and even then had to be reprocessed in the laboratory to some extent. Arrangements have now been made for the supply of suitable yarns of American manufacture. These will be treated according to the methods which have been developed and will be woven in the experimental cotton mill.

In connection with the cloth treatment it appeared desirable to take advantage if possible of the light-weight cotton cloths which are used for other aeronautical purposes. For instance, a 2-ounce cloth of very high strength is regularly used in the manufacture of airship and balloon envelopes. Generous quantities of this material have been furnished by the Navy Department. Using the first pieces supplied a small scale mercerization apparatus for cloth was developed, which was designed and built at the Bureau of Standards. A large sample of material is now being put through this apparatus. It is planned to make small parachutes from the finished material. These will be tested in comparison with parachutes made of silk cloth and of untreated cotton cloth.

The complete organization for making the yarn on a production scale is being worked out in the experimental cotton mill. A bale of long staple "Arizona-Egyptian" cotton (grown in Arizona) has been purchased and is being processed in the cotton mill. When this yarn is spun it will be handled in the same manner and according to the processes which have been described above. This work will probably require eight months to a year to complete, but in the end will make available fairly complete information as to the possibilities of this method of processing.

#### SUBCOMMITTEE ON AIRCRAFT STRUCTURES

*Welded joints.*—Because of the possibility that metal aircraft structures can be fabricated by welding, at a lower cost and with a saving of weight, the metallurgical and fatigue properties of welds, with particular reference to the strength of specimens fabricated by this process, are being investigated.

Butt welds on sheets of duralumin, carbon steel, and chrome vanadium steel, in four thicknesses, and with three welding processes (atomic hydrogen, oxyacetylene, and electric arc) have been furnished for test.

Preliminary tensile tests on specimens in the "as received" condition, indentation tests, and metallurgical treatments, have been completed. The work has not advanced sufficiently to record any definite conclusions as to the efficiency of these methods of fabrication, but it is

expected that the investigation will ultimately furnish important information as to the availability of these welding processes for load-carrying members of aircraft structures.

*Strength of flat plates.*—The investigation of the column strength of flat plates of nickel, duralumin, stainless steel, and monel metal was decided upon as a result of the increasing use of metal construction in which the shell plating is required to carry part of the load. Very little information exists as to the manner in which the compressive loads in such a shell are carried, and as a preliminary step toward a solution of this problem the column strengths of flat plates of the different materials mentioned are being determined. In this investigation the effect of variations in width alone is being considered. The plates are always flat, and while the edges are fixed in position they are not fixed in direction.

*Form factors for tubing of duralumin and steel under combined column and beam loads.*—This research was undertaken to increase the amount of information available as to the loads which could be sustained by steel and duralumin tubing when used either in the fuselage or other structure of an airplane. Work on one size of duralumin tubing has been completed and curves prepared for the use of the designer. Work on the steel tubing in three sizes is still under way.

*Structures for airships.*—The compression tests made upon a *Shenandoah* type spiral latticed girder and a special girder with opposite latticing to determine the relative importance of the principal elastic constants of the chord members, i. e., the flexural stiffnesses (moments of inertia  $\times$  Young's modulus) in the directions of the two principal axes of inertia and the torsional stiffness (torsion constant  $\times$  shear modulus) showed that the characteristic wavy flexure of these girders under load was almost wholly a twist of the channel section; that restraining this twist without restraining the lateral deflections or spread of the flanges increased the carrying capacity of the girder by over 40 per cent; and that therefore the torsional stiffness of the channels was the major controlling factor in the strength of the girder.

Complete tests have been made upon nine specimens involving approximately 23,000 individual measurements. Those made upon *Shenandoah* type triangular spiral latticed girders having differing moments of inertia, area of channels, and character of restraints offered by the lattices, have confirmed these results within the range of girders tested. They have also been confirmed by tests on the square *Shenandoah* type girder, having angles for the chord members, where the load-carrying capacity of this type of girder was increased over 35 per cent upon restraint of the twist without in any way restraining the lateral deflection.

The results have also been confirmed by tests on four short sections of experimental girders with tubular chord members but otherwise identical with the Zeppelin type-55 series of *Shenandoah* girders. In these tubular type girders the moments of inertia and areas of the sections are not greatly different from those of the channel sections but the torsional stiffness is very much higher. The failure shows no effect of twisting, being of the mixed elastic and yielding flexural type characteristic of columns of medium slenderness (Karman range) with average stresses approaching the yield point of the material.

Like columns of medium slenderness the failure does not show the rapid collapse after the maximum load characteristic of the purely elastic flexural type of failure found with open channels. Each of the three was compressed a few tenths of an inch beyond the maximum, under decreasing load and increasing bending of the tubular chords. On release of load the girder lengthened with straightening of the bent chords, leaving only a small part of the curvature remaining as permanent deformation. There was, however, no evidence of the "pick up" found in certain ranges of solid columns.

Further tests are planned on two box girders such as are used in parts of the *Los Angeles* and upon several experimental box girders of similar design which have been fabricated at the Lakehurst Naval Air Station.

*Fittings.*—The Department of Commerce in administering the inspection and airworthiness provisions of the air commerce act of 1926, has found that there is great diversity in the manner in which fittings, for metal or wooden construction, are made in commercial practice. It accordingly requested the Bureau of Standards to investigate this subject with a view to improving the methods of design and construction and, if possible, introducing some simplification in the practice. The Bureau of Standards has referred the question to this subcommittee and recommendations are being prepared which will probably include a program of research.

## PART IV

### TECHNICAL PUBLICATIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics has issued technical publications during the past year covering a wide range of subjects. There are four series of publications, namely, Technical Reports, Technical Notes, Technical Memorandums, and Aircraft Circulars.

The Technical Reports present the results of fundamental research in aeronautics carried on in different laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aerodynamical laboratory at the Washington Navy Yard, the Bureau of Standards, the Weather Bureau, Stanford University, and the Massachusetts Institute of Technology. In all cases the reports were recommended for publication by the technical subcommittees having cognizance of the investigations. During the past year 26 Technical Reports were issued.

Technical Notes present the results of small research investigations and the results of studies of specific detail problems which form parts of long investigations. The committee has during the past year issued in mimeographed form 18 Technical Notes.

Technical Memorandums contain translations and reproductions of important aeronautical articles of a miscellaneous character. A total of 50 Technical Memorandums were issued during the past year.

Aircraft Circulars contain translations or reproductions of articles descriptive of new types of aircraft. During the past year 40 Aircraft Circulars were issued.

Summaries of the 26 Technical Reports and lists of the Technical Notes, Technical Memorandums, and Aircraft Circulars issued during the past year follow.

#### SUMMARIES OF TECHNICAL REPORTS

The first annual report of the National Advisory Committee for Aeronautics for the fiscal year 1915 contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; the twelfth annual report, Nos. 233 to 256; and since the preparation of the twelfth annual report for the year 1926 the committee has authorized the publication of the following Technical Reports, Nos. 257 to 282.

*Report No. 257*, entitled "Pressure Distribution Over a Wing and Tail Rib of a VE-7 and of a TS Airplane in Flight," by J. W. Crowley, jr., National Advisory Committee for Aeronautics.—This investigation was made at the Langley Memorial Aeronautical Laboratory, to determine the pressure distribution over a rib of the wing and over a rib of the horizontal tail surface of an airplane in flight and to obtain information as to the time correlation of the loads occurring on these ribs. Two airplanes, VE-7 and TS, were selected in order to obtain the information for a thin and a thick wing section. In each case the pressure distribution was recorded for the full range of angle of attack in level flight and throughout violent maneuvers. Particular attention was given to the high and low angle of attack conditions. The results show: (a) That the present rib load specifications in use by the Army Air Corps and the Bureau of Aeronautics, Navy Department, are in fair agreement with the loads actually occurring in flight, but could be slightly improved; (b) that there appears to be no definite sequence in which wing and tail surface ribs reach their respective maximum loads in different maneuvers; (c) that in accelerated flight, at air speeds less than or equal to 60 per cent of the maximum speed, the

accelerations measured agree very closely with the theoretically possible maximum accelerations. In maneuvers at higher air speeds the observed accelerations were smaller than those theoretically possible.

*Report No. 258*, entitled "Some Factors Affecting the Reproducibility of Penetration and the Cut-off of Oil Sprays for Fuel Injection Engines," by E. G. Beardsley, National Advisory Committee for Aeronautics.—This investigation was undertaken at the Langley Memorial Aeronautical Laboratory, in connection with a general research on fuel-injection engines for aircraft. The purpose of the investigation was to determine the factors controlling the reproducibility of spray penetration and secondary discharges after cut-off.

The development of single sprays from automatic injection valves was recorded by means of special high-speed photographic apparatus capable of taking 25 consecutive pictures of the moving spray at a rate of 4,000 per second. The effects of two types of injection valves, injection-valve tube length, initial pressure in the injection-valve tube, speed of the injection control mechanism, and time of spray cut-off, on the reproducibility of spray penetration, and on secondary discharges were investigated.

It was found that neither type of injection valve materially affected spray reproducibility. The initial pressure in the injection-valve tube controlled the reproducibility of spray penetrations. An increase in the initial pressure or in the length of the injection-valve tube slightly increased the spray penetration within the limits of this investigation. The speed of the injection-control mechanism did not affect the penetration.

Analysis of the results indicates that secondary discharges were caused in this apparatus by pressure waves initiated by the rapid opening of the cut-off valve. The secondary discharges were eliminated in this investigation by increasing the length of the injection-valve tube.

*Report No. 259*, entitled "Characteristics of Propeller Sections Tested in the Variable Density Wind Tunnel," by Eastman N. Jacobs, National Advisory Committee for Aeronautics.—Tests were carried out in the variable density wind tunnel at the Langley Memorial Aeronautical Laboratory on six airfoil sections used by the Bureau of Aeronautics as propeller sections. The sections were tested at pressures of 1 and 20 atmospheres corresponding to Reynolds Numbers of about 170,000 and 3,500,000. The results obtained, besides providing data for the design of propellers, should be of special interest because of the opportunity afforded for the study of scale effect on a family of airfoil sections having different thickness ratios.

*Report No. 260*, entitled "The Effect of a Flap and Ailerons on the N. A. C. A. M6 Airfoil Section," by George J. Higgins and Eastman N. Jacobs, National Advisory Committee for Aeronautics.—This report contains the results obtained at the Langley Memorial Aeronautical Laboratory, on an N. A. C. A. M6 airfoil, fitted with a flap and ailerons, and tested in the variable-density wind tunnel at a density of 20 atmospheres. Airfoil characteristics are given for the model up to  $48^\circ$  angle of attack with the flap set at various angles, and also with the ailerons set at similar angles. The approximate lift distribution and the center of pressure variation along the span are determined with the model at  $18^\circ$  angle of attack and with the ailerons displaced  $20^\circ$ . Approximate rolling moment and yawing moment coefficients are determined for the various aileron settings.

A comparison of the calculated angles of zero lift and the calculated lift and moment coefficients with those observed is given in the appendix.

*Report No. 261*, entitled "Resistance and Cooling Power of Various Radiators," by R. H. Smith, construction department, Washington Navy Yard.—This report combines the wind-tunnel results of radiator tests made at the Navy aerodynamical laboratory in Washington during the summers of 1921, 1925, and 1926. In all, 13 radiators of various types and capacities were given complete tests for figure of merit. Twelve of these were tested for resistance to water flow and a fourteenth radiator was tested for air resistance alone, its heat-dissipating capacity being known. All the tests were conducted in the 8 by 8 foot tunnel, or in its 4 by 8 foot restriction, under conditions as nearly the same as possible. That is to say, as far as possible, the general arrangement and condition of the apparatus, the observation intervals, the ratio of water flow per unit of cooling surface, the differential temperatures, and the air speeds were the

same for all. Also, for reasons of comparison, the  $L/D$  value of 6, which was assumed in the 1921 tests as the  $L/D$  of the airplane using the radiator, was also used in the more recent tests.

No attempt is made to enter upon the theory of heat dissipation. Only the actual test results are given and reduced to coefficient form. The precision of the tests as representative of full-flight performance is definitely known only in the case of the HN-2. The McCook Field full-flight performance and the Navy tunnel performance of this radiator agree within about 3 per cent.

Since this full-flight test was made with unusual care and since the wind-tunnel tests on all the radiators were made not only accurately but also at almost full scale, it would seem probable that these tests represent quite accurately the full-flight performances in actual service.

*Report No. 262*, entitled "Friction of Aviation Engines," by S. W. Sparrow and M. A. Thorne, Bureau of Standards.—The first portion of this report discusses measurements of friction made in the altitude laboratory of the Bureau of Standards between 1920 and 1926 under research authorization of the National Advisory Committee for Aeronautics. These are discussed with reference to the influence of speed, barometric pressure, jacket-water temperature, and throttle opening upon the friction of aviation engines. It is concluded that: (1) Changes in friction due to changes in the temperature of the air entering the engine are negligible. (2) Changes in friction which result from changes in atmospheric pressure are due primarily to changes in pumping loss. An approximate figure for the engines mentioned in this report is that the friction mean effective pressure decreases about one-tenth of a pound per square inch for each decrease of 1 centimeter of mercury in the barometric pressure. (3) The increase in friction resulting from a decrease in throttle opening is due to the change in pumping loss. For the engines mentioned in this report, the change in friction mean effective pressure which accompanies a change in manifold suction of 1 inch (2.54 centimeters) of mercury ranges from 0.20 pound per square inch obtained at an engine speed of 1,200 revolutions per minute to 0.39 at 1,800 revolutions per minute. (4) For the range of speeds covered in this report, namely, from 1,000 to 2,200 revolutions per minute, the friction mean effective pressure increases with speed, but ordinarily the percentage increase is less than the corresponding percentage increase in speed. At low engine speeds the friction mean effective pressure changes much less with change in speed and in some instances remains practically constant. (5) Friction depends upon the viscosity of the oil upon the cylinder walls, which in turn depends upon the temperature of the jacket water. (6) While theoretical considerations would lead one to expect an increase in friction with increase in compression ratio the evidence at hand indicates that this effect is slight.

The second section of the report deals with measurements of the friction of a group of pistons differing from each other in a single respect, such as length, clearness, area of thrust face, location of thrust face, etc. Results obtained with each type of piston are discussed and attention is directed particularly to the fact that the friction chargeable to piston rings depends upon piston design as well as upon ring design. This is attributed to the effect of the rings upon the thickness and distribution of the oil film which, in turn, affects the friction of the piston to an extent which depends upon its design.

*Report No. 263*, entitled "Preliminary Flight Tests of the N. A. C. A. Roots Type Aircraft Engine Supercharger," by Arthur W. Gardiner and Elliott G. Reid, National Advisory Committee for Aeronautics.—An investigation of the suitability of the N. A. C. A. Roots type aircraft engine supercharger to flight-operating conditions, as determined by the effects of the use of the supercharger upon engine operation and airplane performance, is described in this report.

The supercharger has been previously described in N. A. C. A. Technical Report No. 230; the results of laboratory tests are also given there. The compressor has a displacement of 0.51 cubic foot per revolution and weighs 88 pounds.

The selection of a suitable propeller and the provision of satisfactory intake ducts and adequate engine cooling were preliminary problems. The supercharger was first tested in a modified DH-4 airplane with a 5.4-compression-ratio Liberty-12 engine. Two sets of drive

gears which enabled the maintenance of sea-level pressure at the carburetor intake up to 12,000 and 20,000 feet were provided. The higher gear ratio supercharger was next tested in a DT-2 landplane which was later converted into a twin-float seaplane; the DT-2 also had a Liberty engine. Loads up to 2,000 pounds were carried in the seaplane with normal and supercharged engines.

Attention was concentrated on the operation of the engine-supercharger unit and on the improvement of climbing ability; some information concerning high speeds at altitude was obtained.

The supercharger was found to be satisfactory under flight-operating conditions. Although two failures occurred during the tests, the causes of both were minor and have been eliminated. Careful examination of the engines revealed no detrimental effects which could be attributed to supercharging.

Marked improvements in climbing ability and high speeds at altitude were effected. It was also found that the load which could be carried to a given moderate or high altitude in a fixed time was considerably augmented. A slight sacrifice of low-altitude performance was necessitated, however, by the use of a fixed pitch propeller.

From a consideration of the very satisfactory flight performance of the Roots supercharger and of its inherent advantages, it is concluded that this type is particularly attractive for use in certain classes of commercial airplanes and in a number of military types.

*Report No. 264*, entitled "Differential Pressures on a Pitot-Venturi and a Pitot-Static Nozzle over 360° Pitch and Yaw," by R. M. Bear, construction department, Washington Navy Yard.—Measurements of the differential pressures on two Navy air-speed nozzles, consisting of a Zahm type Pitot-Venturi tube and a SQ-16 two-pronged Pitot-static tube, in a tunnel air stream of fixed speed at various angles of pitch and yaw between 0° and  $\pm 180^\circ$ , show for a range over  $-20^\circ$  to  $+20^\circ$  pitch and yaw, indicated air speeds varying very slightly over 2 per cent for the Zahm type and a maximum of about 5 per cent for the SQ-16 type from the calibrated speed at 0°.

For both types of air-speed nozzle the indicated air speed increases slightly as the tubes are pitched or yawed several degrees from their normal 0° attitude, attains a maximum around  $\pm 15^\circ$  to  $25^\circ$ , declines rapidly therefrom as  $\pm 40^\circ$  is passed, to zero in the vicinity of  $\pm 70^\circ$  to  $100^\circ$ , and thence fluctuates irregularly from thereabouts to  $\pm 180^\circ$ . The complete variation in indicated air speed for the two tubes over 360° pitch and yaw is graphically portrayed in Figures 9 and 10.

For the same air speed and 0° pitch and yaw the differential pressure of the Zahm type Pitot-Venturi nozzle is about seven times that of the SQ-16 type two-pronged Pitot-static nozzle.

*Report No. 265*, entitled "A Full-Scale Investigation of Ground Effect," by Elliott G. Reid, National Advisory Committee for Aeronautics.—This report describes flight tests which were made with a Vought VE-7 airplane to determine the effects of flying close to the ground.

It is found that the drag of an airplane is materially reduced upon approaching the ground and that the reduction may be satisfactorily calculated according to theoretical formulas.

Several aspects of ground effect which have had much discussion are explained.

*Report No. 266*, entitled "Air Force and Moment for N-20 Wing with Certain Cut-Outs," by R. H. Smith, construction department, Washington Navy Yard.—The airplane designer often finds it necessary, in meeting the requirements of visibility, to remove area or to otherwise locally distort the plan or section of an airplane wing. This report, prepared for the Bureau of Aeronautics, January 15, 1925, contains the experimental results of tests on six 5 by 30-inch N-20 wing models, cut out or distorted in different ways, which were conducted in the 8 by 8-foot wind tunnel of the Navy Aerodynamical Laboratory in Washington in 1924.

The measured and derived results are given without correction for  $VL/\nu$  or for wall effect and for standard air density,  $\rho = 0.00237$  slug per cubic foot.

*Report No. 267*, entitled "Drag of Wings with End Plates," by Paul E. Hemke, National Advisory Committee for Aeronautics.—In this report a formula for calculating the induced drag of multiplanes with end plates is derived. The frictional drag of the end plates is also

calculated approximately. It is shown that the reduction of the induced drag, when end plates are used, is sufficiently large to increase the efficiency of the wing.

Curves showing the reduction of drag for monoplanes and biplanes are constructed; the influence of gap-chord ratio, aspect ratio, and height of end plate are determined for typical cases. The method of obtaining the reduction of drag for a multiplane is described.

Comparisons are made of calculated and experimental results obtained in wind-tunnel tests with airfoils of various aspect ratios and end plates of various sizes. The agreement between calculated and experimental results is good.

Analysis of the experimental results shows that the shape and section of the end plates are important.

*Report No. 268*, entitled "Factors in the Design of Centrifugal Type Injection Valves for Oil Engines," by W. F. Joachim and E. G. Beardsley, National Advisory Committee for Aeronautics.—This research was undertaken at the Langley Memorial Aeronautical Laboratory, in connection with a general study of the application of the fuel injection engine to aircraft. The purpose of the investigation was to determine the effect of four important factors in the design of a centrifugal type automatic injection valve on the penetration, general shape, and distribution of oil sprays.

The general method employed was to record the development of single sprays by means of special high-speed photographic apparatus capable of taking 25 consecutive pictures of the moving spray at a rate of 4,000 per second. Investigations were made concerning the effects on spray characteristics of the helix angle of helical grooves, the ratio of the cross-sectional area of the orifice to that of the grooves, the ratio of orifice length to diameter, and the position of the seat. The sprays were injected at 6,000, 8,000, and 10,000 pounds per square-inch pressure into air at atmospheric pressure and into nitrogen at 200, 400, and 600 pounds per square-inch pressure. Orifice diameters from 0.012 to 0.040 inch were investigated.

It was found that decreasing the pitch of the helical grooves and thus increasing the centrifugal force applied to the spray increased the spray cone angle considerably, although the percentage increase was much less in dense air than in the atmosphere. On the other hand, the spray penetration decreased with increase in the amount of centrifugal force applied. About twice as much spray volume per unit oil volume was obtained with a high centrifugal spray as with a noncentrifugal spray. The spray cone angle increased, and the spray volume to oil volume ratio and spray penetration decreased with increase in the ratio of orifice area to groove area. Maximum spray penetration was obtained with a ratio of orifice length to diameter of about 1.5. Slightly greater penetration was obtained with the seat directly before the orifice.

*Report No. 269*, entitled "Air Force Tests of Sperry Messenger Model with Six Sets of Wings," by James M. Shoemaker, National Advisory Committee for Aeronautics.—The purpose of this test was to compare six well-known airfoils, the R. A. F. 15, U. S. A. 5, U. S. A. 27, U. S. A. 35-B, Clark Y, and Göttingen 387, fitted to the Sperry Messenger model at full-scale Reynolds Number as obtained in the variable-density wind tunnel of the National Advisory Committee for Aeronautics; and to determine the scale effect on the model equipped with all the details of the actual airplane. The results show a large decrease in minimum drag coefficient upon increasing the Reynolds Number from about one-twentieth scale to full scale. Maximum lift coefficient was increased with increasing scale for all the airfoils except the Göttingen 387, for which it was slightly decreased. A comparison is made between the results of these tests and those obtained from tests made in this tunnel on airfoils alone.

*Report No. 270*, entitled "The Measurement of Pressure through Tubes in Pressure Distribution Tests," by Paul E. Hemke, National Advisory Committee for Aeronautics.—The tests described in this report were made to determine the error caused by using small tubes to connect orifices on the surface of aircraft to central pressure capsules in making pressure-distribution tests.

Aluminum tubes of three-sixteenths inch inside diameter were used to determine this error. Lengths from 20 feet to 226 feet and pressures whose maxima varied from 2 inches to 140 inches

of water were used. Single-pressure impulses for which the time of rise of pressure from zero to a maximum varied from 0.25 second to 3 seconds were investigated.

The results show that the pressure recorded at the capsule on the far end of the tube lags behind the pressure at the orifice end and experiences also a change in magnitude. For the values used in these tests the time lag and pressure change vary principally with the time of rise of pressure from zero to a maximum and the tube length. Curves are constructed showing the time lag and pressure change. Empirical formulas are also given for computing the time lag.

Analysis of pressure-distribution tests made on airplanes in flight shows that the recorded pressures are slightly higher than the pressures at the orifice and that the time lag is negligible. The apparent increase in pressure is usually within the experimental error, but in the case of the modern pursuit type of airplane the pressure increase may be 5 per cent. For pressure-distribution tests on airships the analysis shows that the time lag and pressure change may be neglected.

*Report No. 271*, entitled "Pressure Distribution Tests on PW-9 Wing Models Showing Effects of Biplane Interference," by A. J. Fairbanks, National Advisory Committee for Aeronautics.—In this report tests are described in which the distribution of pressures over models of the wings of the PW-9 airplane was investigated. The wing models were tested individually and in the biplane combination. The investigation was conducted in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics. It is concluded in this paper that the effect of biplane interference on the pressures on the wings is practically confined to the lower surface of the upper wing and the upper surface of the lower wing; that the overhanging portion of the upper wing is not greatly affected by the presence of the lower wing; and that a slight washin at the center section of the upper wing satisfactorily compensates for a reduced chord at this section (providing the airfoil section is not mutilated) and prevents a large reduction in the normal force over this portion of the wing.

*Report No. 272*, entitled "The Relative Performance Obtained with Several Methods of Control of an Overcompressed Engine Using Gasoline," by Arthur W. Gardiner and William E. Whedon, National Advisory Committee for Aeronautics.—This report presents some results obtained at the Langley Memorial Aeronautical Laboratory during an investigation to determine the relative performance characteristics for several methods of control of an overcompressed engine using gasoline and operating under sea-level conditions. For this work, a special single-cylinder test engine, 5-inch bore by 7-inch stroke, and designed for ready adjustment of compression ratio, valve timing and valve lift while running, was used. This engine has been fully described in N. A. C. A. Technical Report No. 250.

Tests were made at an engine speed of 1,400 revolutions per minute for compression ratios ranging from 4 to 7.6. The air-fuel ratios were on the rich side of the chemically correct mixture and were approximately those giving maximum power. When using plain domestic aviation gasoline, detonation was controlled to a constant, predetermined amount (audible), such as would be permissible for continuous operation, by (a) throttling the carburetor, (b) maintaining full throttle but greatly retarding the ignition, and (c) varying the timing of the inlet valve to reduce the effective compression ratio. For the first and third methods, the throttle opening and the valve timing, respectively, were adjusted so that the ignition timing could be advanced slightly beyond the advance, giving maximum power without exceeding the standard of permissible detonation. The optimum performance for the engine when using a nondetonating fuel, consisting of 80 per cent of commercial benzol and 20 per cent of aviation gasoline, was obtained as a basis for comparison.

The following comparative results are based on the optimum performance for the engine obtained with the nondetonating fuel at a compression ratio of 4.7. The power and fuel consumption with method (b) remained substantially constant at the higher compression ratios, the order of the ignition timing permitting full throttle operation ranging from 30° at 4.7 to 3° at 7.3; exhaust temperatures, heat loss to the cooling water, and explosion pressures at the higher ratios were normal. At a compression ratio of 7.5, the power obtained with method (a) was about 39 per cent less and the fuel consumption was considerably lower; with method

(b), time of inlet-valve opening constant and time of inlet-valve closing varied, the power was about 23 per cent less and the fuel consumption was greatly increased; with method (c), time of inlet opening and closing varied simultaneously, the power was about 29 per cent less and the fuel consumption was greatly increased.

From these results, it may be concluded that method (c) gives the best all-round performance and, being easily employed in service, appears to be the most practicable method for controlling an overcompressed engine using gasoline at low altitudes.

*Report No. 273*, entitled "Wind Tunnel Tests on Autorotation and the 'Flat Spin,'" by Montgomery Knight, National Advisory Committee for Aeronautics.—This report deals with the autorotational characteristics of certain differing wing systems as determined from wind-tunnel tests made at the Langley Memorial Aeronautical Laboratory. The investigation was confined to autorotation about a fixed axis in the plane of symmetry and parallel to the wind direction. Analysis of the tests leads to the following conclusions:

Autorotation below  $30^\circ$  angle of attack is governed chiefly by wing profile and above that angle by wing arrangement.

The strip method of autorotation analysis gives uncertain results between maximum  $C_L$  and  $35^\circ$ .

The polar curve of a wing system, and to a lower degree of accuracy the polar of a complete airplane model are sufficient for direct determination of the limits of rotary instability, subject to strip-method limitations.

The results of the investigation indicate that in free flight a monoplane is incapable of flat spinning, whereas an unstaggered biplane has inherent flat-spinning tendencies.

The difficulty of maintaining equilibrium in stalled flight is due primarily to rotary instability, a rapid change from stability to instability occurring as the angle of maximum lift is exceeded.

*Report No. 274*, entitled "The N. A. C. A. Photographic Apparatus for Studying Fuel Sprays from Oil Engine Injection Valves and Test Results from Several Researches," by Edward G. Beardsley, National Advisory Committee for Aeronautics.—Apparatus for recording photographically the start, growth, and cut-off of oil sprays from injection valves has been developed at the Langley Memorial Aeronautical Laboratory. The apparatus consists of a high-tension transformer by means of which a bank of condensers is charged to a high voltage. The controlled discharge of these condensers in sequence, at a rate of several thousand per second, produces electric sparks of sufficient intensity to illuminate the moving spray for photographing. The sprays are injected from various types of valves into a chamber containing gases at pressures up to 600 pounds per square inch.

Several series of pictures are shown. The results give the effects of injection pressure, chamber pressure, specific gravity of the fuel oil used, and injection-valve design upon spray characteristics.

*Report No. 275*, entitled "The Effect of the Walls in Closed Type Wind Tunnels," by George J. Higgins, National Advisory Committee for Aeronautics.—A series of tests has been conducted during the period 1925–1927 by the National Advisory Committee for Aeronautics in the variable density wind tunnel on several airfoil models of different sizes and sections to determine the effect of tunnel-wall interference and to determine a correction which can be applied to reduce the error caused thereby. The use of several empirical corrections was attempted with little success. The Prandtl theoretical corrections give the best results, and their use is recommended for correcting closed wind-tunnel results to the conditions of free air.

An appendix is attached wherein the experimentally determined effect of the walls on the tunnel velocity very close to their surface is given. This is of special interest because a "scale effect" was found in the boundary layer with a change in the density of the tunnel air.

*Report No. 276*, entitled "Combustion Time in the Engine Cylinder and Its Effect on Engine Performance," by Charles F. Marvin, jr., Bureau of Standards.—As part of a general program to study combustion in the engine cylinder and to correlate the phenomena of combustion with the observed performance of actual engines, this paper, which was outlined by

S. W. Sparrow, and the work undertaken at the request of the National Advisory Committee for Aeronautics, presents a sketchy outline of what may happen in the engine cylinder during the burning of a charge. It also suggests the type of information needed to supply the details of the picture and points out how combustion time and rate affect the performance of the engine.

A theoretical concept of a flame front which is assumed to advance radially from the point of ignition is presented, and calculations based on the area and velocity of this flame and the density of the unburned gases are made to determine the mass rate of combustion. From this rate the mass which has been burned and the pressure at any instant during combustion are computed.

This process is then reversed in an effort to determine actual rates of combustion and flame velocities from the pressures as recorded on indicator diagrams.

The effects of different rates of combustion on engine performance are then discussed and the importance of proper spark advance is emphasized.

*Report No. 277*, entitled "The Comparative Performance of an Aviation Engine at Normal and High Inlet Air Temperatures," by Arthur W. Gardiner and Oscar W. Schey, National Advisory Committee for Aeronautics.—This report presents some results obtained at the Langley Memorial Aeronautical Laboratory during an investigation to determine the effect of high inlet air temperature on the performance of a Liberty-12 aviation engine. The purpose of this investigation was to ascertain, for normal service carburetor adjustments and a fixed ignition advance, the relation between power and temperature for the range of carburetor air temperatures that may be encountered when supercharging to sea-level pressure at altitudes of over 20,000 feet and without intercooling when using plain aviation gasoline and mixtures of benzol and gasoline.

Laboratory tests were made at full throttle over the speed range from 1,400 to 1,800 revolutions per minute, in which the pressure at the carburetor and exhaust was maintained sensibly constant and the inlet air temperature varied from 45° to 180° F. The range of mixtures was that normally used in flight. Plain aviation gasoline, a mixture consisting of 30 per cent (by volume) of commercial benzol and 70 per cent gasoline, and a mixture of 65 per cent benzol and 35 per cent gasoline were used. Additional tests were made with a Wright E-4 aviation engine.

The results show that for the conditions of test, both the brake and indicated power decrease with increase in air temperature at a faster rate than given by the theoretical assumption that power varies inversely as the square root of the absolute temperature. On a brake basis, the order of the difference in power for a temperature difference of 120° F. is 3 to 5 per cent. The observed relation between power and temperature when using the 30 to 70 blend was found to be linear. But, although these differences are noted, the above theoretical assumption may be considered as generally applicable except where greater precision over a wide range of temperatures is desired, in which case it appears necessary to test the particular engine under the given conditions.

*Report No. 278*, entitled "Lift, Drag, and Elevator Hinge Moments of Handley-Page Control Surfaces," by R. H. Smith, construction department, Washington Navy Yard.—This report combines the wind-tunnel results of tests on four control surface models made in the two wind tunnels of the Navy aerodynamical laboratory, Washington Navy Yard, during the years 1922 and 1924. The purpose of the tests was to compare, first, the lifts and the aerodynamic efficiencies of the control surfaces from which their relative effectiveness as tail planes could be determined; then the elevator hinge moments upon which their relative ease of operation depended. The lift and drag forces on the control surface models were obtained for various stabilizer angles and elevator settings in the 8 by 8 foot tunnel by the writer in 1922; the corresponding hinge moments were found in the 4 by 4 foot tunnel by Mr. R. M. Bear in 1924.

*Report No. 279*, entitled "Tests on Models of Three British Airplanes in the Variable Density Wind Tunnel," by George J. Higgins and George L. DeFoe, National Advisory Committee for Aeronautics, and W. S. Diehl, Bureau of Aeronautics, Navy Department.—This report contains the results of tests made in the National Advisory Committee for Aeronautics

variable density wind tunnel on three airplane models supplied by the British Aeronautical Research Committee. These models, the BE-2E with R. A. F. 19 wings, the Bristol Fighter with R. A. F. 15 wings, and the Bristol Fighter with R. A. F. 30 wings, were tested over a wide range in Reynolds Numbers in order to supply data desired by the Aeronautical Research Committee for scale-effect studies.

The maximum lifts obtained in these tests are in excellent agreement with the published results of British tests, both model and full scale. No attempt is made to compare drag data, owing to the omission of tail surfaces, radiator, etc., from the model, but it is shown that the scale effect observed on the drag coefficients in these tests is due to a large extent to the parts of the models other than the wings.

*Report No. 280*, entitled "The Gaseous Explosive Reaction—The Effect of Inert Gases," by F. W. Stevens, Bureau of Standards.—(1) Attention is called in this report to previous investigations of gaseous explosive reactions carried out under constant volume conditions, where the effect of inert gases on the thermodynamic equilibrium was determined. The advantage of constant pressure methods over those of constant volume as applied to studies of the gaseous explosive reaction is pointed out and the possibility of realizing for this purpose a constant pressure bomb mentioned.

(2) The application of constant pressure methods to the study of gaseous explosive reactions, made possible by the use of a constant pressure bomb, led to the discovery of an important kinetic relation connecting the rate of propagation of the zone of explosive reaction within the active gases, with the initial concentrations of those gases:  $s = k_1 [A]^{n_1} [B]^{n_2} [C]^{n_3}$ .

(3) By a method analogous to that followed in determining the effect of inert gases on the equilibrium constant  $K$ , the present paper records an attempt to determine their kinetic effect upon the expression given above. It is found that this effect for the inert gases investigated— $N_2$ , He, and  $CO_2$ —may be expressed as

$$s = k_1 [A]^{n_1} [B]^{n_2} [C]^{n_3} - - - + \beta G_1$$

where  $G_1$  represents the initial concentration of the inert gas. From results obtained it seems probable that the value of  $\beta$  depends upon the combined effect of the thermal properties of the inert gas on the heat distribution of the reaction, the property of heat conductivity being predominant.

(4) An example of the utility of the constant pressure bomb for the study of the kinetics of the gaseous explosive reaction is offered in the results of the present paper.

*Report No. 281*, entitled "The Effects of Fuel and Cylinder Gas Densities on the Characteristics of Fuel Sprays for Oil Engines," by William F. Joachim and Edward G. Beardsley, National Advisory Committee for Aeronautics.—This investigation was conducted at the Langley Memorial Aeronautical Laboratory as a part of a general research on fuel-injection engines for aircraft. The purpose of the investigation was to determine the effects of fuel and cylinder gas densities upon several characteristics of fuel sprays for oil engines.

The start, growth, and cut-off of single fuel sprays produced by automatic injection valves were recorded on photographic film by means of special high-speed motion-picture apparatus. This equipment, which has been described in previous reports, is capable of taking 25 consecutive pictures of the moving spray at the rate of 4,000 per second.

The penetrations of the fuel sprays increased and the cone angles and relative distributions decreased with increase in the specific gravity of the fuel. The density of the gas into which the fuel sprays were injected controlled their penetration. This was the only characteristic of the chamber gas that had a measurable effect upon the fuel sprays. Application of fuel-spray penetration data to the case of an engine, in which the pressure is rising during injection, indicated that fuel sprays may penetrate considerably farther than when injected into a gas at a density equal to that of the gas in an engine cylinder at top center.

*Report No. 282*, entitled "The Performance of Several Combustion Chambers Designed for Aircraft Oil Engines," by William F. Joachim and Carlton Kemper, National Advisory Committee for Aeronautics.—Several investigations have been made on single-cylinder test engines

at the Langley Memorial Aeronautical Laboratory to determine the performance characteristics of four types of combustion chambers for aircraft oil engines. Two of the combustion chambers studied were bulb-type precombustion chambers, the connecting orifice of one having been designed to produce high turbulence by tangential air flow in both the precombustion chamber and the cylinder. The other two were integral combustion chambers, one being dome-shaped and the other pent-roof shaped. The injection systems used included cam and eccentric driven fuel pumps and diaphragm and spring-loaded fuel-injection valves. A diaphragm-type maximum cylinder pressure indicator has been used in part of these investigations with which the cylinder pressures were controlled to definite values. The performance of the engines when equipped with each of the combustion chambers is discussed. The data presented show the performance for speeds from 600 to 1,800 revolutions per minute.

The results obtained indicate that aircraft type oil engines with suitably designed combustion chambers and fuel-injection systems may be operated at speeds around 1,800 revolutions per minute without encountering excessive explosion pressures. At a speed of 1,600 revolutions per minute and with a fuel quantity giving 15 per cent excess air in the cylinder, a maximum indicated mean effective pressure of 119 pounds per square inch was obtained with a fuel consumption of 0.43 pound per indicated horsepower per hour. The maximum cylinder pressure was 740 pounds per square inch. A minimum fuel consumption of 0.26 pound per indicated horsepower per hour at an indicated mean effective pressure of 52 pounds per square inch and 1,600 revolutions per minute was obtained with a cylinder head having a bulb-type precombustion chamber. The maximum cylinder pressure was 560 pounds per square inch.

It is concluded that an increase in specific power output of the high-speed aircraft oil engine depends upon the ability to obtain higher mean effective pressures and an improvement in the mechanical efficiency of the engine. The best performance for the tests reported was obtained with a bulb-type combustion chamber designed to give a high degree of turbulence within the bulb and cylinder.

#### LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

- No.
248. The Drag of Airships. By Clinton H. Havill, United States Navy. Part II. Drag of Bare Hulls.
  249. Effect of Protruding Gasoline Tanks Upon the Characteristics of an Airfoil. By Eastman N. Jacobs.
  250. Influence of the Orifice on Measured Pressures. By Paul E. Hemke.
  251. The Effect of Tube Length Upon the Recorded Pressures from a Pair of Static Orifices in a Wing Panel. By T. Carroll and R. E. Mixon.
  252. Resistance of a Fifteen-Centimeter Disk. By James M. Shoemaker.
  253. Wind Tunnel Standardization Disk Drag. By Montgomery Knight.
  254. Method of Correcting Wind Tunnel Data for Omitted Parts of Airplane Models. By R. H. Smith.
  255. Precision of Wing Sections and Consequent Aerodynamic Effects. By Frank Rizzo.
  256. Wall Interference in Closed Type Wind Tunnels. By George J. Higgins.
  257. Technical Preparation of the Airplane "Spirit of St. Louis." By Donald A. Hall.
  258. A Warning—Concerning the Take-Off with Heavy Load. By Elliott G. Reid and Thomas Carroll.
  259. "Alclad"—A New Corrosion-Resistant Aluminum Product. By E. H. Dix, jr.
  260. Study of Open Jet Wind Tunnel Cones. By Fred E. Weick.
  261. Tension Experiments on Diaphragm Metals. By H. B. Henrickson.
  262. The Installation and Correction of Compasses in Airplanes. By M. F. Schoeffel.
  263. A Load Factor Formula. By Roy G. Miller.
  264. Tests of the N. P. L. Airship Models in the Variable-Density Wind Tunnel. By George J. Higgins.
  265. Measurement of the Moments of Inertia of Full-Scale Airplanes. By M. W. Green.
  266. Airfoil Lift with Changing Angle of Attack. By Elliott G. Reid.

## LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

- No.
382. Experiments with Rotating Cylinders in Combination with Airfoils. By Kurt Frey. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," August 28, 1926.
383. Spindled and Hollow Spars. By J. D. Blyth. From "Flight," August 26, 1926.
384. Experimental Investigation of the Physical Properties of Medium and Heavy Oils, Their Vaporization and Use in Explosion Engines. By Fritz Heinlein. Part III. Experimental Apparatus. Translation from "Der Motorwagen," June 30, 1926.
385. Cooling of Air-Cooled Engines by Forced Circulation of Air. Translation from "Les Ailes," September 9, 1926.
386. Central Aerohydrodynamic Institute of Moscow, Russia. By W. Margoulis. Translation from "L'Aeronautique," August, 1926.
387. Approximate Calculation of the Static Longitudinal Stability of Airplanes. By Theodor Bienen. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," July 28, 1926.
388. Experiments with a Sphere from Which the Boundary Layer is Removed by Suction. By Oskar Schrenk. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," September 14, 1926.
389. Devices for Prevention of Stalled Flight. By Paul Mazer. Translation from "L'Aeronautique," October, 1926.
390. Determining Size of Drops in Fuel Mixture of Internal-Combustion Engines. By J. Sauter. Translation from "Zeitschrift des Vereines deutscher Ingenieure," July 31, 1926.
391. Experiments on Self-Ignition of Liquid Fuels. By Kurt Neumann. Translation from "Zeitschrift des Vereines deutscher Ingenieure," August 7, 1926.
392. Experimental Investigation of the Physical Properties of Medium and Heavy Oils, Their Vaporization and Use in Explosion Engines. By Fritz Heinlein. Part IV. Translation from "Der Motorwagen," September 30 and November 10, 1926.
393. Stall-Proof Airplanes. By G. Lachmann. From Yearbook of "Wissenschaftlichen Gesellschaft für Luftfahrt," 1925.
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- No.  
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Part I. Determination of the Main Conditions Entailing Overload and Examination of the Existing Theoretical and Experimental Data.  
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Part III. Load Factors.  
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404. The Protection of Duralumin from Corrosion. By Wm. Nelson. From "Aviation," November 8, 1926.
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  425. Recent Suggestions in Diesel-Engine Construction. By F. Ernst Bielefeld. Translation from "Schiffbau," June 2, June 16, and July 7, 1926.
  426. Seaplane Floats and Hulls. By H. Herrmann. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," December, 1926.
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  428. Drag Measurements on a Junkers Wing Section. Application of the Betz Method to the Results of Comparative Tests Made on a Model and on an Airplane in Flight. By Hanns Weidinger. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," December, 1926.
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  430. Effect of Roughness on Properties of Airfoils. By O. Schrenk. Translation from Report III, "Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen," 1927.
  431. Experiments on Airfoils with Trailing Edge Cut Away. By J. Ackeret. Translation from Report III, "Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen," 1927.

## LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

- No.
17. The Avro Avian Airplane. From "Flight," August 26, 1926.
  18. The De Havilland *Moth*. From "Flight," March 5, 1925.
  19. The Bristol *Badminton* Airplane. From "Flight," July 8, 1926.
  20. The Handley-Page *Hamlet* (Commercial Monoplane). From "The Aeroplane," October 13, 1926, and "Flight," October 14, 1926.
  21. The A. N. E. C. IV *Missel Thrush*, Light Airplane. From "Flight," September 9, 1926.
  22. Avia Pursuit Airplane *B. H. 21*. By J. Serryer. Translation from "Les Ailes," May 28, 1925.
  23. Albert *TE-1*, Training Airplane. Translation from the French.
  24. Rohrbach All-Metal Commercial Airplane *RO VIII*, "Roland." Translation from the German.
  25. The Supermarine *Southampton*, Seaplane (Observation or Bomber). From "Flight," November 18 and 25, 1926.
  26. The Boulton and Paul *Bugle*, Airplane (Day Bomber). From "Flight," April 23, 1925, and "The Aeroplane," April 29, 1925.
  27. Dyle and Bacalan Metal Monoplane *D. B. 10* (Night Bomber). Translation from "Les Ailes," December 2, 1926, and "L'Aerophile," November, 1926.
  28. Combat and Bombing Airplane, Amiot 120 *B3*. Translation from a circular issued by the S. E. C. M. ("Societe d'Etudes et de Constructions Mecaniques").
  29. Nieuport-Delage 48 *C1*, Pursuit Airplane ("Jockey" Type). Translation from the French.
  30. The Dornier *Mercury*, Commercial Airplane. From a circular issued by the Dornier Co.
  31. Dornier *Superwal*, Commercial Seaplane. From "I. F. W." No. 21, 1926, and from a circular issued by the Dornier Co.
  32. Macchi *M. 39*, Seaplane (Single Seat Racer). Translation from "L'Ala d'Italia," November, 1926.
  33. "Savoia" Seaplane *S. 55* (Military or Commercial). From a circular issued by the "S. I. A. I." and "Flight," April 9, 1925.

- No.
34. Vojenska-Smolik *S. 16*, Airplane (All-Metal Long-Distance Observation Biplane). From "Flight," January 13, 1927.
  35. Richard-Penhoet Commercial Seaplane. Translation from "Bulletin de la Chambre Syndicale des Industries Aeronautiques," September-December, 1926.
  36. The Rohrbach "Robbe" *RO VII*, Seaplane (Military or Commercial). From a circular issued by the Rohrbach Metal Aeroplane Co.
  37. The Francois Villiers Marine Pursuit Airplane. From a circular issued by Villiers Co., supplemented from article in "Les Ailes," November 25, 1926.
  38. Heinkel *H. E. 5*, Commercial Seaplane (Winner of the 1926 German Seaplane Contest at Warnemunde). From a circular issued by the Ernst Heinkel Airplane Co.
  39. Lioré-Olivier *LeO 194*, Seaplane. Translation from "L'Aéronautique," February, 1927.
  40. Training Airplane *Avia B.-H. 11*. Translation from a circular issued by Milos Bondy A Spol, Czechoslovakia.
  41. *Meteore 63* Commercial Seaplane. From a circular issued by the S. P. C. A. with supplementary data from "Les Ailes," July 29, 1926.
  42. The Mureaux *Brunet 302*, Pursuit Airplane. By J. Serryer. Translation from "Les Ailes," March 24, 1927.
  43. Fiat *C. R. 20*, Pursuit Airplane. Translation from "L'Ala d'Italia," December, 1926.
  44. The Rohrbach *Rocco*, Seaplane (New German Commercial Seaplane). From "Flight," May 12, 1927.
  45. The Blackburn *Bluebird* (Two-Seat Training and Sport Airplane). From "The Aeroplane," March 16, 1927.
  46. Focke-Wulf *G. L. 18* (Commercial Airplane). By J. Serryer. Translation from "Les Ailes," September 23, 1926.
  47. Junkers Airplane *G. 24* (All-Metal Commercial Airplane). Translation from a circular issued by the "Junkers Flugzeugwerk, A. G.," of Dessau, Germany.
  48. The Gloster *Gambet*, Airplane (A Deck-Landing Ship's Fighter). From "The Aeroplane," June 1, 1927.
  49. The Avro "Gosport" *504 R* (A New Training Airplane). From "Flight," April 15, 1926.
  50. *Levasseur 8*, Transatlantic Airplane. Translation from "L'Aéronautique," June, 1927, and "L'Aerophile," June, 1927.
  51. Caproni Airplane *Ca 73* (Commercial) and *Ca 73 ter* (Military). Translation from a circular issued by the Caproni Co., Milan, Italy.
  52. The Boeing Mail Airplane. Prepared by the Boeing Airplane Co.
  53. The Westland *Widgeon III*. From "Flight," July 28, 1927.
  54. Junkers Commercial Airplane *G. 31*. Translation from "Zeitschrift des Vereines deutscher Ingenieure," May 7, 1927.
  55. *Travel Air*, Commercial Airplane—Type 5000. Prepared by Travel Air Manufacturing Co.
  56. Training Airplane *Arado SC 1*. Translation from "Flugwoche," June 22, 1927.

#### BIBLIOGRAPHY OF AERONAUTICS

During the past year the committee issued bibliographies of aeronautics for the years 1923 and 1924. It had previously issued bibliographies for the years 1909 to 1916, 1917 to 1919, 1920 to 1921, and 1922. A bibliography for the year 1925 is now in the hands of the printer, and should be ready for distribution during the coming year. An annual bibliography will be published hereafter by the committee.

Citations of the publications of all nations are included in the language in which the publications originally appeared. The arrangement is in dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross reference to make possible the finding of items in special lines of research.

## PART V

### THE PRESENT STATE OF AERONAUTICAL DEVELOPMENT

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#### PROGRESS IN TECHNICAL DEVELOPMENT

##### . AERODYNAMICS

The nature and results of the fundamental research carried out in the various laboratories during the past year emphasize the fact that the main theoretical foundation of this science has been laid and that new advances must be more in the nature of extensions or additions to existing theory rather than new fundamental conceptions. The majority of the aerodynamic problems investigated during the past year were closely identified either with particular design requirements or with the study of unusual phenomena. A well-balanced program should include as much fundamental research as possible, but continuing demands for answers to specific problems have made it impossible to give proper consideration to fundamental research. The work done during the past year and that laid out for the future may appear to contain only a small proportion of fundamental research, but careful analysis will show that almost every investigation, in addition to the possibility of some immediate practical application as one of its objects, has a bearing on some fundamental problem. It will readily be understood that the committee's research program must be arranged to suit the technical requirements of the services and the equipment and personnel available.

**WIND TUNNELS.—*Airplane model tests.***—The wind tunnel continues to grow in the esteem of aeronautical engineers as its value becomes more generally recognized. Additional confirmation has recently been obtained of the necessity for either strict geometrical similarity or due allowance for lack of it. The first tests on the Sperry Messenger model in the variable-density wind tunnel gave drag coefficients very much less than the full-scale values obtained from flight tests. A comparison of the model with the full-scale airplane showed that a number of small parts and minor details had been omitted in the model. When these had been incorporated in the model a much better agreement was found. One of the first investigations in the new propeller research equipment was on the full-scale Sperry Messenger with wings removed, and the drag values were found to be about 10 per cent higher than those given by the variable-density wind tunnel for the same model condition.

It was found that the Sperry Messenger model did not have a fair representation of the landing-gear details, particularly in regard to the axle and shock absorbers. When these were faired in on the full-scale airplane in accordance with the model construction, excellent agreement in drag values was obtained. Several laboratories now allow for deviation from full scale in the model construction, and in particular the Washington Navy Yard wind tunnels have long made it a regular practice to apply a calculated drag correction for omitted detail, thereby securing consistent agreement between model and full-scale values.

***Variable-density wind tunnel.***—During the past year tests were made in the variable-density wind tunnel on three airplane models supplied by the British Aeronautical Research Committee. These models had previously been tested in various wind tunnels in England and the actual airplanes tested in free flight. The results obtained in the variable-density wind tunnel were in excellent agreement with the British data, both model and full scale. One of the most important lessons learned from these tests is that the scale effect on lift may be very large in airfoils which are very thick, very deeply cambered, or of symmetrical section. In particular, the high maximum lift at low Reynolds Number on a very thick or deeply cambered section is not likely to be obtained at high Reynolds Numbers.

*Autorotation.*—The research on autorotation has been continued with what appears to be definite results. After measuring rates of spin under various conditions it was found that they did not agree with the rates calculated by the "strip method." The angular ranges for spin instability were widely different as obtained by experiment and calculation. This feature was investigated thoroughly by means of pressure distribution studies and the variation of loading along the span was found to account for the differences. As a by-product of this investigation some very valuable load distribution data are being made available.

Included in the autorotation research were a number of tests on various airfoils in varying combinations leading to several conclusions worthy of note. The most important of these is that no monoplane model has been found which will "flat spin," and it does not appear likely that one will be found. The flat spin may be due either to the geometry of the wing cellule or to mass distribution in combination with the geometry (i. e., little or no stagger). An approximate criterion of spinning instability which is very easy to apply was developed during this research.

*Boundary layer control.*—A considerable amount of research work has been done on boundary layer control, both pressure and suction methods being used. In explanation of this research, Doctor Prandtl showed that the disturbance originating in a thin layer of air adjacent to the wing surface was the cause of the flow breaking away from the upper surface at high angles of attack and thus preventing the attainment of high lifts.

"Boundary layer control" is descriptive of the means employed to prevent the flow from breaking away. Air may be forced through small slots running across the upper surface of the wing and so formed that the jet is approximately parallel with the wing surface at the exit, or forward opening slots may be used with suction instead of pressure. From the standpoint of power absorbed the suction method has given the best results but slightly higher maximum lifts have been obtained with the pressure method. The greatest increase in maximum lift so far obtained is about 50 per cent but this was obtained on a wing section now known to be unsuited for the purpose, and further tests under way may be expected to show better results.

*FREE FLIGHT TESTS.—Pressure distribution.*—During the past year free flight work has followed the general program of the year before in that a large number of investigations have been completed and new projects initiated. The success of the studies made on the TS-1 and VE-7 airplanes led to an extension and expansion of program on pursuit airplanes in which an Army Boeing PW-9 and a Navy Curtiss F6C-4 have been used. Very complete records have been obtained in various maneuvers, giving linear and angular velocities and accelerations at various parts of the airplane, together with pressure distributions on wings and tail surfaces. Many important facts bearing on design requirements have been obtained. Special attention has been given to loads on the horizontal tail surfaces in diving and in quick pull-ups from diving at high speed, to the variation of loading along the span under various conditions, and to the distribution of loading over the two wings of a biplane. This work is made possible by the use of special photographic equipment so designed that continuous and simultaneous records are obtained for all desired factors in any maneuver. Engineers who are in touch with these developments are of the opinion that pressure distribution studies along these lines offer the most logical and promising method available for increasing our knowledge of design requirements.

*Boundary layer control.*—Free flight tests have been made on the TS-1 airplane fitted with the pressure system of boundary layer control in the upper wing only, the pressure being supplied by a supercharger blower. The results showed a rather small but quite definite improvement in climb without appreciable change in high speed. One feature of particular interest was that air speed for best climb was reduced about 10 miles per hour when the blower was operating. In view of the fact that the slots were installed on one wing only and that the wing section (U. S. A.-27) was shown by wind-tunnel tests to be unfavorable for this purpose, it is believed that boundary layer control may offer some promise and further work will be done.

*Spinning.*—One of the most important free flight investigations was carried out by the Army Air Corps at McCook Field during the past year. As a part of the general study of spinning, the effect of changing the location of the center of gravity in a systematic manner

ranging from about 17 to 39 per cent of the mean chord, together with the effect of various mass distributions was tried on two airplanes, the O-1 and the O2-E4. Spins were made in both directions under all conditions and the control position for recovery, altitude lost per turn, turns for recovery, etc., were noted in each case. Recovery in every case was assured by fitting the airplane with one or more boxes of lead shot which could be dropped so as to bring the center of gravity forward. It was found that as the center of gravity moved aft the airplane would spin slower and more down at the nose while the control forces increased. At a center of gravity location of approximately 38 per cent the control forces became so great and the response of the airplane so slow that the spin was considered dangerous and tests were discontinued. It was shown that mass distribution played a most important part in holding the airplane in a spin.

*Landing and take-offs.*—The study of the landing and take-off characteristics of various airplanes is being continued. At present tests are being made on a Douglas mail airplane to determine the effect of variations in the load and changes of the propeller characteristics on taking off and landing.

*Pressure distribution on floats.*—The water pressures over the bottom of the UO-1 seaplane float have been obtained in a great number of landings and this work is to be continued on a TS-1. The maximum intensity so far measured is less than 7 pounds per square inch. Readings are taken at a sufficient number of points to enable the drawing of an accurate load-contour map.

*Improvement in visibility.*—A VE-7 airplane with the center section of the upper wing cut away and the spars replaced by streamline struts for the purpose of improving the visibility was tested to determine the effect of the changes on the performance of the airplane. It was found that the rate of climb was reduced about 12 per cent which is in agreement with the increase in induced drag. As predicted, the high speed was affected less than 2 per cent. These values were but slightly improved by the use of "end planes" on the "inner" tips.

*Control at low speeds.*—Flight research on lateral control at low speeds was confined to the continuation of the spoiler-gear tests on the TS-1 airplane. Owing to the urgency of other work this research has not yet been completed. A number of additional tests on lateral control at low speeds have been proposed and it is probable that a definite program will be adopted during the present year.

*PROPELLERS.*—The recent completion of the propeller research equipment opens up an entirely new field of opportunity for propeller research. Preliminary tests on the Sperry messenger airplane indicate that a great number of problems involving power plant and fuselage design can now be solved. The testing program now under way includes check tests on the VE-7 propellers previously tested in flight, a study of propeller blade deflections under various flight conditions, a study of the effect of various forms of cowling on the resistance and cooling of air-cooled engines, and the determination of proper forms for wind shields and cowling.

*Comparative tests on a model.*—A metal model propeller supplied by Charles Ward Hall has been tested at Stanford University and will be tested in the wind tunnels at the Massachusetts Institute of Technology and the National Physical Laboratory, in order to obtain comparative data under different test methods and in open and closed types of wind tunnels. The matter of correction due to tunnel wall interference has received serious consideration in England and this series of tests will fit in with the general investigation.

*LIGHTER-THAN-AIR CRAFT.*—*Pressure distribution in flight.*—The most important lighter-than-air investigation completed during the past year was the flight pressure distribution runs on the rigid airship U. S. S. *Los Angeles*. It was found that the maximum loadings on tail surfaces due to gusts is greater than the maximum loadings obtained in maneuvers.

*Fineness ratio.*—The tests in the variable-density wind tunnel on a series of airship models of varying fineness ratio have been completed. In this research, each model was tested at various Reynolds Numbers, thus covering a very large range, previously unexplored. A special wire-type drag balance which was designed and installed for these tests gave such consistent results that several streamline models which had previously been tested on the regular balance

were retested with rather surprising results. One model in particular which had shown an extremely low drag in the original test was found to have a normal drag on the wire balance. The difference was easily shown to be due to spindle interference in the first tests.

**FIELDS FOR FUTURE RESEARCH.**—It is plain that continued progress in aerodynamics may be expected but that it will be largely along lines leading to refinements in design. Every detail of an airplane may be improved in this manner, both structurally and aerodynamically. The most promising fields of future research are those which increase our knowledge of the magnitude and distribution of the forces acting on an airplane. Research along these lines should lead to more efficient structures and greater safety, through better control, and to the development of better wing sections free from unstable flow characteristics. The study of the causes of discontinuous flow and of the effects of slots, flaps, and "boundary layer control" will also lead to better control at low speeds.

The immediate needs of the designer are for information which will promote this refinement of design. Important items in this information are the effects of the mutual interference between the propellers and other parts of the airplane in both single and multi-engined airplanes; the effect of the mutual interference between the wings, fuselage, and landing gear; and the effect of the cowling around the forward end of the fuselage on both the cooling of air-cooled engines and the drag of the airplane. The designer also requires more data on wings, especially data obtained in full-scale tests, including the distribution of pressure over the wings.

#### AIRPLANE STRUCTURES

**TREND OF DESIGN.**—*Standardization of types.*—The tendency toward the standardization of types for particular services has continued. The monoplane has definitely established itself for commercial service where air speeds are relatively low and efficiency is the prime requirement. It also has the advantages of easy maintenance and giving good visibility to passengers together with good ground clearance under the wing when on the landing field. In the lighter and faster types of commercial airplanes where moderate loads or only one or two passengers are carried the biplane continues to be preferred, as might be expected from the advantages it confers in the way of maneuverability and compactness of form.

For military airplanes the biplane combination continues in the lighter types where semi-internally braced and moderately thick wings are used. In pursuit airplanes a modification of the biplane, with the lower wing smaller than the upper, approximating the sesquiplane, appears to be the general practice. By this construction great compactness is obtained while the structural strength required by the demand for extreme speed and maneuverability is obtained with the lightest weight. The biplane cellule also continues for shipboard airplanes since the span of such an airplane can not exceed 50 feet owing to the limitations fixed by handling devices. While last year the biplane cellule was uniform in observation and bombing types the development of the monoplane type has been begun and a number of this type are now undergoing service tests.

*Number and location of engines.*—The use of several engines in large military aircraft is now standard practice. This is in general accord with the commercial practice for large airplanes which is definitely established as using several engines, generally three. A single engine continues to be used in commercial airplanes with a capacity of up to six passengers where a larger number of engines would be uneconomic or impracticable.

*Amphibian airplanes.*—Interest in the development of the amphibian type of airplane has been very much increased by the discovery that in many cases our lakes and rivers provide a series of favorable seaplane landing places, along traveled routes. The amphibian can take advantage of such a natural airway and also can land its passengers on a regular landing field. In addition it can propel itself from the water up a beach, either natural or artificial, thus doing away with both handling cradles and crews.

The successful development of the amphibian is due to the successful use of light alloys, which has made it possible to reduce the weight of structure, and to the use of the air-cooled engine. It is now possible to construct amphibians having a performance comparable with

that of other types. Several manufacturers are working on the development of amphibian airplanes for commercial purposes.

*Differences between military and commercial types.*—The differences in the fundamental requirements of military and commercial types of airplanes have been appreciated more clearly. This is evidenced by the fact that the construction of commercial airplanes in a plant entirely separate and distinct from that in which military airplanes are built has been proposed.

In the military types also an understanding of the differences between the fundamental requirements of aircraft for Army and Navy use is more apparent. Special equipment of Navy types enabling them to be projected from catapults and landed on arresting gear requires a considerably heavier structure and details in many parts than in the corresponding Army types. Consequently it is frequently found that a Navy airplane apparently identical with an Army type will weight several hundred pounds more than its Army duplicate.

The specialization which differentiates the military type so markedly from the commercial type of airplane has continued. It is now apparent that the great majority of commercial airplanes built in this country could not be adapted to any purely military use. Certain of the lighter and faster types might be used for preliminary training and some of the heavier ones might be used for transport purposes but neither would have a truly military character.

*Landing gear—Shock absorbers.*—Hydraulic shock absorbers are practically universal on military airplanes and have come into almost general use in commercial airplanes. As a rule it is only the smaller and lighter types of commercial airplanes which still retain the old rubber cord shock absorbers.

*Brakes.*—With the increasing appreciation of the necessity for proper handling of airplanes on the ground, both in taking-off and landing, brakes have undergone a very considerable further development and at present there are several good designs on the market. They are being generally applied to all types of airplanes, both military and commercial and are being used not only for landing but also in place of wheel chocks just before taking-off. Many pilots find it advantageous to run the engine up to full revolutions with the brakes on and then suddenly release them. This results in a shorter take-off run. The possibility of combining the use of brakes on the wheels of the regular landing gear with a wheel in place of the usual skid and the fitting of a brake on this wheel is engaging attention. This is particularly appreciated since the destructive effect of the ordinary skid on landing fields which handle much traffic has become apparent.

The combination of the shock absorbers and the brakes in the wheel has been proposed and has been tried out experimentally in military airplanes. This arrangement would be extremely desirable on account of the reduction in resistance and its development is being watched with interest.

*STRUCTURAL MATERIALS.—Metal construction.*—Even the smallest and lightest commercial airplanes now have a metal fuselage. In fact a wooden longeron fuselage is a comparative rarity.

The introduction of metal into the wing construction has not become so general, since it has been attended with considerable difficulties. Metal spars of aluminum alloy and steel have been constructed which show a very satisfactory weight as compared with wooden ones. However, the difficulties which have been experienced in the proper protection of the aluminum alloys against corrosion has prevented their full utilization especially in types of structures where inspection is difficult. With the introduction of aluminum alloys which are practically free from corrosion difficulties an expansion of this use is probable.

The most notable all-metal airplanes are usually original in design and details of construction. It should be noted that most of these airplanes use aluminum alloys and have done so for long periods with practically no serious difficulty regarding corrosion.

*Steel tubing.*—Corrosion in steel tubing has always been a disturbing factor. Many methods of protection have been proposed and tried but none has proved entirely satisfactory. The development of extremely high-strength and corrosion-resisting steel tubing has been proposed. This type of tubing will require special methods of welding, but great interest in the possibilities

has been displayed by the manufacturers of the material and by the manufacturers of the devices used in welding.

*Duralumin tubing.*—The use of duralumin tubing has decreased owing to the difficulties encountered in protecting the interior of the tubing from corrosion. Structural sections of H and I form have been substituted for tubing in many instances.

*Floats.*—The metal float has continued to gain in favor, particularly since the practical freedom from increase of weight caused by soakage means a permanent reduction in weight. With the development of a satisfactory method of protection against corrosion it is probable that this method of constructing floats will become standard.

*Rubber protective coatings.*—Considerable improvements in these coatings have been made and it is confidently expected that they will have an important place in the protection of aluminum and other parts of aircraft. The resistance of rubber to abrasion would appear to be particularly valuable in connection with floats on seaplanes and amphibians where the aircraft must be handled up and down on beaches.

#### AIRSHIPS

*Technical development and present situation.*—The technical development of airships continues to lag behind that of airplanes. This is only to be expected in view of the small numbers of airships which are built and the very limited opportunity for development of new ideas and methods of construction which are presented. No new airship construction has been begun in the United States. Attention has been confined to the replacement of parts of existing nonrigid airships.

A design competition was held by the Navy Department looking toward the procurement of the best designs for the 6,000,000-cubic-foot airships which have been authorized by Congress as a part of the Navy Department "five-year aviation program." A number of designs were submitted, among them a very satisfactory one, and negotiations toward a contract for the construction of one airship generally according to this design are under way. This design includes a number of features which, while novel as far as actual incorporation in airships is concerned, have been commonly discussed in that connection for many years.

Experimental investigation and research for the purpose of improving existing airships and providing improved materials and methods of construction for new airships whenever they are begun has continued although at a decreased rate. The satisfactory methods for the protection of duralumin against corrosion and progress made in the obtaining of substitutes for goldbeater's skin fabric are the most notable results.

*Work with the "Los Angeles."*—The *Los Angeles* has been maintained in splendid condition and undoubtedly has several years of useful and active life before it. It has been used frequently in research on problems connected with the design and operation of rigid airships. One of the most important problems was the determination of the effect on the speed of the airship of fitting water recovery apparatus. For this purpose a series of deceleration tests was carried out on the airship both with and without the water recovery apparatus. The resistance coefficients of the full-sized airship were thus determined and the effect of the added apparatus was accurately determined.

The operating personnel of the *Los Angeles* has been continuously active in the improvement of methods for handling airships on the ground and in and out of the shed. The enlisted and officer personnel engaged in this work have been very highly complimented by persons who have observed the manner in which this airship has been handled by the methods now in use. As a result of study by the personnel at Lakehurst there has been developed a method using a mobile telescopic mast and a large amount of mechanical equipment which it is expected will make it possible to reduce the number of men required for landing and handling the airship to a very notable degree. This equipment is now being constructed and it is expected will be tested in the coming year.

*Work with "RS-1."*—This airship has made several notable flights from its home station at Scott Field, including one to Langley Field and Lakehurst. It has been extremely active in spite of the handicap imposed on it by a very heavy power plant.

Steps are now being taken toward the redesign of the power plant, including the substitution of two new engines in place of the four now in use, together with the corresponding simplification and lightening in weight. No reverse gears are to be fitted but the propellers are to be made reversing.

The nose cone originally fitted, having shown indications of weakness, has been replaced by a new nose cone of an improved design which has operated with entire satisfaction. When the proposed modifications have been completed this airship should be very much improved in performance.

*Metal-clad airship.*—Progress on the design and construction of this airship, which is being supplied to the Navy Department by the Aircraft Development Corporation of Detroit, has been reported.

*New mooring masts.*—The mooring mast constructed at Scott Field, Belleville, Ill., by the Aircraft Development Corporation has been tried out and found to be very successful. The construction of this type of mast has been found to be very much simpler and to be capable of being carried out with much more rapidity than any previous type. At the same time it affords complete protection to the elevator and pipe lines inclosed within it. It also has a pleasing appearance, being a slender tube much like a smokestack.

*Helium.*—The Army has acquired an additional helium tank car and further tank cars are being considered by both the Army and the Navy. The savings from the use of these cars are very considerable and it is obvious that the tank cars are a very valuable help in the conservation of the helium supply.

A portable helium purification plant mounted upon railroad cars has been placed in service by the Army Air Corps. With this plant all that is necessary is to connect suitable openings on the car to electric leads, water, and helium lines from the impure helium and to storage. It has operated with great satisfaction and turned out helium of high purity.

A privately owned helium plant has been constructed and is now producing helium at a cost which compares favorably with the cost of helium produced in Government-owned plants. The Navy Department is taking practically the entire production of this plant. The owners propose to increase the capacity of the plant in the near future, which will make available a still greater quantity of helium. This plant draws its supply of gas from a field in Kansas. The supply of helium from this field will probably be limited but is large enough to be an important factor in the present available supply.

The gas production in the Petrolia field which supplies the Fort Worth plant has been somewhat improved by cleaning out wells. It has been found that many wells were badly filled and by the simple process of attaching orifice meters to each well it has been possible to select the wells to be cleaned. This has led to a very gratifying increase in the amount of raw gas supplied to the plant and a corresponding increase in the production of helium.

However, the necessity for the location of new supplies of helium and the adoption of proper measures for conservation and development still remained. Accordingly, steps have been taken by the Bureau of Mines leading toward the development of a large new field in northwest Texas. This field is practically untouched and if its entire supply can be exploited in an economical manner, as planned, processing all the gas, it is estimated that it contains a quantity of helium-bearing gas amply sufficient to serve the Nation's needs for several generations.

*Progress in Great Britain.*—Good progress has been made on the construction of the two 5,000,000-cubic-foot airships in Great Britain. These two airships have undergone numerous changes in design as work progressed, but it is understood that they are expected to be ready for flight in the first half of 1928.

The erection of an airship shed at Karachi, India, is well under way, while the mooring masts at Karachi; Ismailia, Egypt; and Cardington, England, are completed.

At the Imperial Conference held in England in October, 1926, emphasis was laid upon the importance of air transport and a system of imperial air communication. Airships were con-

sidered to play an important rôle in this matter and the data revealed by the report of the air delegates to the conference show that Great Britain has developed her airship program with great care and very thoroughly. An effort was made to interest several of the colonies in the establishment of mooring masts. Apparently Australia, Canada, and South Africa are showing considerable interest in establishing such masts. It was reported that a site for a mast has already been selected in Canada.

*Progress in Germany.*—The rigid airship having a capacity of about 3,500,000 cubic feet which has been under construction in Germany for the past year is reported to be near completion and may even take the air before the airships which are building in Great Britain.

*Progress in Italy.*—Information from Italy indicates that the large semirigid airship of about 53,000 cubic meters to which reference was made in last year's report has not been begun, although plans have been prepared for it. Just when its actual construction will be begun appears uncertain.

*Standardization of mooring mast equipment.*—In view of the probable international character of airship navigation efforts have been made looking toward the standardization of mooring masts. The amount of standardization required is not very great as it would involve primarily the mooring cone and the arrangement and method of operation of the mooring lines. With this accomplished an airship would be able to moor with facility to any mast which it might visit. This effort is still in the preliminary stages but it should lead to valuable results.

#### AIRCRAFT ENGINES

The greatly increased activity during the past year in the manufacture and operation of privately owned airplanes using engines originally designed and developed for the military services is evidence of the sound and farsighted policy of the Government services which have fostered and borne the expense of the development of new and better types of aircraft engines.

In the development of aircraft engines for military purposes particular stress has been laid on the reduction in weight and the improvement of the safety factor. The engines thus developed are well suited for use in commercial aviation. Light weight and a maximum of safety are most important aids in the economic success of commercial aviation. The one insures profitable loads and the other certainty of operation.

Several years ago the Navy Department decided to concentrate its efforts on the development of an air-cooled engine. As a result of this decision we now have an air-cooled engine combining light weight with extreme dependability and ruggedness.

Air-cooled engines which have been tested and have proved their value are now available in three powers, 200, 400, and 500 horsepower. The 200-horsepower Wright "Whirlwind" engine, which has been used on all the transoceanic flights from the United States, is now widely used in commercial activities throughout the country and has been one of the most important, if not the most important, contributing factor in the development of efficient, dependable, and comparatively moderate-priced commercial and privately owned aircraft.

The larger 400-horsepower radial air-cooled engine was designed for military purposes and is now finding its way in the commercially owned and operated aircraft, notably in the Chicago to the west coast air mail-service.

The still larger 500-horsepower radial air-cooled engine is now taking its place in flight service in the Navy and will be available for commercial purposes in the near future.

During the past year there has been a notable increase in the development by private capital of air-cooled engines especially adapted to commercial service. Several engines of 80 to 150 horsepower are under development. The Fairchild "Caminez" engine has passed the development stage and is now on the market.

These engines are being purchased for operation in commercial airplanes, notwithstanding the fact that there still remain a considerable number of war-time engines which may be purchased for a nominal sum. This is a most encouraging indication of the healthy condition of the commercial aircraft industry, as it shows that the industry has reached the stage where

private capital is building on its own initiative special types of airplanes and airplane engines without financial assistance from governmental agencies.

Further developments are being made, with the assistance of the Government, to decrease the weight per horsepower and increase the dependability and efficiency of aircraft engines. Higher compression ratios and improved fuels are being used with success in military service operation.

In the field of water-cooled aircraft engines no new types have been developed during the past year. Proved engines of from 200 to 800 horsepower are available and have been further developed by the addition of reduction gears and refinements permitting operation at high speeds. A number of engines of the water-cooled type are now designed so as to operate over long periods at speeds up to 3,000 revolutions per minute.

The past year has seen the beginning of the general service use of the supercharger, and it may now be said that the supercharger for aircraft engines has passed definitely out of the research stage and is in the engineering production stage. The development of light-weight and dependable reduction gears for propellers is progressing satisfactorily and they will no doubt be in extensive use on military types of aircraft engines in the near future. Following the supercharger, special engine fuels and reduction gears will no doubt be adapted to commercial purposes when they have shown their value in military types of aircraft.

#### SUMMARY

The year 1927 was notable in demonstrating the capabilities of aircraft. The transoceanic flights of Lindbergh and others led to the awakening of the American people to the possibilities of aviation and to the need for airports. Industrial capital was invested in aeronautical enterprises. The essential activities of the Department of Commerce in establishing airways and in regulating and encouraging commercial aviation were factors in this development. The success of the Army and Navy in developing and standardizing military types facilitated the procurement of aircraft and this, with the Government's support of the five-year aircraft programs for the two services, had a stabilizing effect on the industry. The Government provided air-mail service to the people and encouraged commercial air lines by making air-mail contracts with private carriers. Generally speaking, contract air-mail lines were operated on a sound economic basis.

The most significant characteristic of American aviation is the increase in the number of privately owned airplanes and the increase in the number of commercial flying enterprises which are operated without the cash subsidies that support commercial aviation in other countries.

The record of progress in the development of aeronautics for all purposes is the result of the coordinated effort of all interested, including the Congress, the Executive, the Army and Navy, the industry, the Daniel Guggenheim Fund for the Promotion of Aeronautics, educational institutions, the Weather Bureau, the Bureau of Standards, and the National Advisory Committee for Aeronautics. There is a splendid spirit of cooperation in scientific and technical matters in American aeronautics under the active leadership of the National Advisory Committee. The committee is continuing its scientific researches on the fundamental problems of flight and is distributing scientific and technical data resulting from its investigations and from investigations conducted in other countries. In this way the committee is marshalling the maximum effort of the Nation in the study of the basic problems of aeronautics. The year's record of substantial progress along rational lines is largely the result of the Government's sound aeronautic policy.

It is difficult adequately to draw a word picture of the effect that aeronautics is destined to have on the economic life of the Nation. Progress is being made steadily in the solution of the basic problems of greater safety and of reduction of cost. Where the radius of the average daily social life was once generally limited by walking distances, it has been successively increased by the horse, the street car, the railroad, and the automobile. In America the airplane is destined to play an important part in further enlarging this radius, and in creating new demands and new standards of life which it is hoped will lead to the development of a greater and a happier country.

## CONCLUSION

It is with pleasure that the committee reports that aeronautical progress in the United States during the past year has surpassed the hopes of a year ago. This is particularly true with reference to the operation of aircraft for the transportation of mail and express on regular schedules; the increase in the private ownership and operation of aircraft; the establishment and equipment of airways; and the development of types of aircraft by the Army and Navy for military and naval purposes. It is our conviction that the present governmental policy in aeronautics is sound in principle and is primarily responsible for the progress that is being made. But the most striking evidence of the year's progress is that aviation is being accepted by the people as a means of transportation and as a business in which industrial capital is being invested.

It must be noted that further substantial progress is dependent largely upon the continuous prosecution of scientific research. The committee, therefore, recognizing its responsibility in this respect, recommends a continuation of the liberal support of its work in the fields of pure and applied research on the fundamental problems of flight.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,  
JOSEPH S. AMES, *Chairman*.